CANADA

DEPARTMENT OF MINES

HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

MINES BRANCH

JOHN MCLEISH, DIRECTOR

Comparative Tests of Various Fuels when Burned in a Domestic Hot-Water Boiler

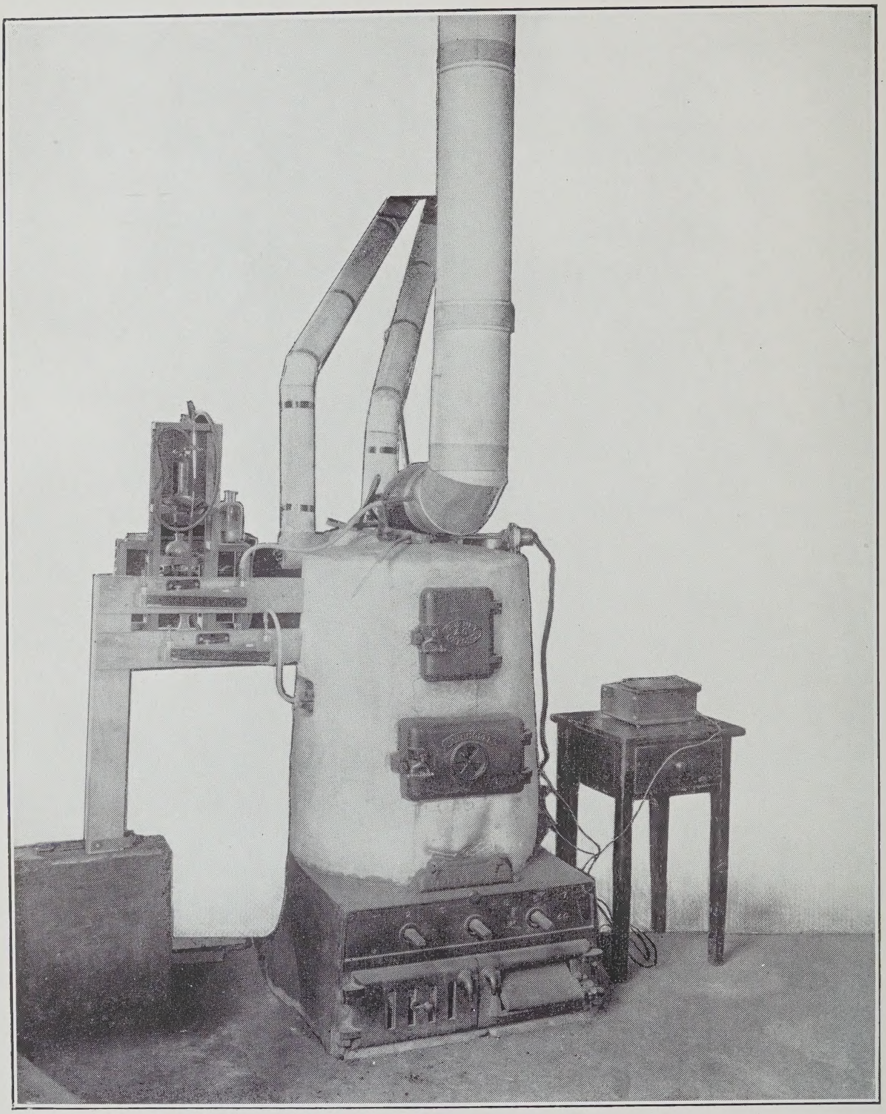
BY

E. S. Malloch and C. E. Baltzer

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1929

No. 705

Price, 20 cents



Original furnace installation.

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COMPARATIVE TESTS OF VARIOUS FUELS WHEN BURNED IN A DOMESTIC HOT-WATER BOILER

INTRODUCTORY

American anthracite has been for many years the most widely used and is, therefore, considered the standard fuel for domestic heating in Ontario and Quebec. The domestic consumer, through long usage, has become thoroughly accustomed to anthracite, so much so that invariably he finds difficulty in adapting himself to the use of auxiliary and substitute fuels when occasion demands. Up to the time of the acute fuel shortage of 1918, auxiliary and substitute fuels had been used only to a small extent to replace American anthracite; but since 1918 the re-occurring shortages of anthracite have stimulated the use of such substitute fuels as have from time to time become available. However, notwithstanding this increased use and consequent greater familiarity with substitute fuels on the part of the consumer, an erroneous idea exists that these fuels are inferior in every respect to American anthracite. This idea is partly due to the dearth of information concerning the comparative values of various fuels when used for domestic heating.

The tests herein described were made in a domestic hot-water boiler by members of the Fuels and Fuel Testing Division of the Mines Branch, Department of Mines, in co-operation with the Dominion Fuel Board for the purpose of obtaining comparative information concerning American anthracite coal and various substitute fuels.

DOMESTIC FUELS

A solid fuel, to fulfil the exacting requirements of general domestic use, must not only be easily obtainable at a reasonable cost, but must also be capable of being burned efficiently in all types of domestic heaters and, when so burned, must keep the house at a uniformly comfortable temperature for at least eight hours without undue attention; and, further, must produce little dust, dirt, smoke, soot, ash, and clinker. Good quality American anthracite fulfils all these conditions, but, unfortunately, the supply and quality at times are uncertain, and the price is high. Accordingly, substitute fuels in the form of coke, briquettes, smokeless semi-bituminous coals, and certain Alberta sub-bituminous and domestic coals are coming into more general use as domestic fuels in Ontario and Quebec. Gradually the consumer is becoming more skilled in the use of these substitutes and in many cases finds them equal, if not superior, to American anthracite.

A wide variety of fuels is used for domestic purposes in Ontario and Quebec. These fuels differ greatly not only in their analyses and calorific values, but also as to their handling, storage, and burning qualities. The main characteristics are shown in a general way in Table I which has been extracted from a paper entitled "Characteristics of Different Types of Canadian Household Fuels"[1], prepared by Messrs. Gilmore, Nicolls, and Kohl[2].

[1]Paper delivered before Ottawa section, Society of Chemical Industry (November, 1922 meeting) and published in Canadian Chemistry and Metallurgy, vol. 7, No. 2, p. 30 (February, 1923).

[2]Superintendent and Engineering Chemists, respectively, of the Department of Mines, Mines Branch, Fuel Testing Laboratories, Ottawa.

TABLE

Chemical Analyses and General

—	Proximate analysis and heat units (air-dried basis)						
	Water %	Ash %	Volatile matter %	Fixed carbon %	Sulphur %	Fuel ratio	B.T.U. per lb.
Pennsylvania anthracite	2·5	11·0	7·0	79·5	0·7	11·2	12,930
Welsh (best grade) anthracite	1·9	4·4	8·3	85·4	1·0	10·2	14,640
Pennsylvania (Connel coal), semi-anthracite	3·4	11·5	8·5	76·6	0·6	9·0	13,150
Welsh (dry) semi-anthracite	1·0	3·0	12·1	83·9	....	6·9	14,880
Alberta (Banff) semi-anthracite	0·8	14·0	10·0	75·2	0·6	7·5	12,900
United States anthracite briquettes	4·0	15·2	9·0	71·8	....	8·0	11,690
Welsh anthracite briquettes	4·3	5·3	10·5	79·9	....	7·6	13,900
Pennsylvania semi-bituminous	1·1	7·4	15·8	75·7	1·5	4·8	14,500
Welsh semi-bituminous	1·0	4·0	18·7	76·3	....	4·1	14,930
Alberta (Canmore) semi-bituminous	2·0	9·3	13·4	75·4	0·9	5·6	13,570
Nova Scotia semi-bituminous	0·9	8·5	16·0	74·6	1·1	4·7	14,260
Pennsylvania bituminous	1·3	9·8	33·9	55·0	2·8	1·6	13,670
Durham (England) bituminous	1·3	6·4	36·3	56·0	2·6	1·5	13,680
British Columbia (Crowsnest Pass) bituminous	1·5	12·5	23·9	62·1	0·5	2·6	12,990
Nova Scotia (Westville) bituminous	1·6	11·3	24·6	63·5	1·5	2·5	13,190
Nova Scotia (Sydney) bituminous	1·9	5·4	34·3	58·4	2·3	1·7	13,770
New Brunswick (Minto) bituminous	0·9	14·3	31·9	52·9	5·7	1·7	12,780
Alberta sub-bituminous	4·0	8·3	37·8	49·9	0·2	1·3	11,790
Alberta (Edmonton, high grade) lignite	18·9	9·3	26·6	45·2	0·4	1·7	8,780
Saskatchewan (Estevan, low grade) lignite	25·8	8·1	30·4	35·7	0·4	1·2	7,980
Nova Scotia metallurgical coke	1·0	8·5	1·7	88·8	1·2	......	13,090
United States metallurgical nut coke	0·9	17·4	2·0	79·7	1·3	......	11,200
Gas coke (Ottawa)	0·8	11·5	1·5	86·2	0·9	......	11,930
Low-temperature coke	0·4	9·3	26·6	63·7	1·2	......	13,450
Peat (air-dried) bricks	24·5	4·7	49·3	21·5	0·2	......	7,150
Peat charcoal	4·7	12·1	27·4	55·8	0·5	......	11,390
Hardwood (average)	(25·0)	(1·0)	(64·5)	(9·5)	....	......	6,480
Hardwood charcoal	5·0	4·0	17·9	73·1	....	......	12,660
Cannel coal	1·5	19·3	45·1	34·1	1·2	......	12,340
Light fuel oil	....	......	....	....	....	......	19,000

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Characteristics of Various Fuels

Average ultimate analysis (ash and moisture-free basis)			Handling, storage, coking, and burning qualities				
Total carbon %	Hydrogen %	Carbon hydrogen ratio	Handling qualities	Storage qualities	Weight, lb. per cu. ft.	Coking qualities	Burning qualities in hard coal furnaces
92·8	3·00	30·9	Very good	Good	55	Non-coking	Good, smokeless
93·5	3·75	24·9	Fair to good	Good	55	Non-coking	Good (when screened) smokeless
91·4	3·80	23·8	Fair to good	Good	47	Non-coking	Fair to good, smokeless
92·6	4·30	21·5	Fair	Good	51	Non-coking	Fair, practically smokeless
90·8	4·10	22·3	Fair to good	Good	....	Non-coking	Fair to good
....	....	....	Fair to good	Good	....	Coking	Fair, some smoke
....	....	....	Fair	Good	51	Non-coking	Good, some smoke
89·6	4·45	20·1	Fair to good	Good	53	Poor coke	Good, some smoke
91·3	4·70	19·4	Fair	Good	52	Fair coke	Good (when screened), some smoke.
89·2	4·45	20·0	Fair to good	Good	....	Poor coke	Good, some smoke
....	....	....	Fair to good	Good	....	Poor coke	Good, some smoke
....	....	....	Fair to good	Fair..	52	Good coke	Good, but very smoky.
....	....	....	Fair to good	Fair	46	Good coke	Good, but very smoky
86·6	4·95	17·6	Fair to good	Fair	....	Good coke	Good, but smoky
86·2	5·15	16·8	Fair to good	Fair	....	Good coke	Good, but smoky
81·9	5·45	15·0	Fair	Fair	....	Good coke	Good, but very smoky
82·1	5·35	15·4	Fair	Fair	53	Fair to good	Good, but very smoky
78·3	4·95	15·9	Good when freshly mined	Fair	....	Non-coking	Fair to good, white smoke
73·8	4·85	15·3	Good to fair	Fair	....	Non-coking	Fair to good, white smoke
69·5	4·95	14·1	Fair to good	Poor	....	Non-coking	Fair, white smoke
....	....	....	Good	Bulky	....	....	Fair, some clinkers, smokeless
....	....	....	Good	Good	39	....	Fair, clinkers, smokeless.
....	....	....	Good	Bulky	32	....	Fair, clinkers, smokeless
....	....	....	Fair to good	Fair	....	....	Fair to good, practically smokeless
....	....	....	Fair to good	Bulky	32	Charcoal	Quick fire, white smoke
....	....	....	Fair	Fair	32	....	Quick fire, smokeless
49·5	6·1	....	Good	Bulky	26	Charcoal	Quick fire, white smoke.
....	....	....	Poor (in bulk)	Fair	16	....	Quick fire, smokeless
....	....	....	Good	Good	50	....	Good only for grate
(85)	(14)	....	....	....	53	....	Good, smokeless

DOMESTIC HEATING SYSTEMS

Domestic heating in Canada is generally done in one of two ways: either by stove or by furnace. Just what proportion of the heating is done by each system is not known, but it is thought that stove-heating installations are by far the more numerous.

STOVE HEATING

Stove heating is general in country districts and also to some extent in cities and towns among the poorer classes, and in such of the older houses as have no basement suitable for the accommodation of a modern furnace plant. With this system one or more stoves are centrally placed on the ground floor of the house in such positions as to provide the necessary radiant heat to keep the rooms in common use comfortable. The upper rooms in the house receive heat by means of the warm air currents rising from the lower rooms and also by radiant heat from the long lines of stove pipe passing through them on their way to the chimney. The principal advantages of stove heating are:—

1. Low first cost of apparatus.
2. Apparatus is easily and cheaply set up.
3. Life of apparatus is long.
4. Repairs to apparatus are easily and cheaply made.
5. Heat is developed just where it is most needed.
6. Ease and quickness of controlling rate of combustion and temperature of room.
7. Economy of operation.

There are, however, disadvantages, some of which are:—

1. Occupation of valuable space.
2. Uncleanliness of operation.
3. Increased labour of attendance.
4. Increased housework due to dust and dirt.

In general, it may be said that for those who desire the most economical heating, the advantages of low cost of equipment, installation, and upkeep, coupled with the greater economy of operation of stoves over other systems of heating, far outweigh the disadvantages.

FURNACE HEATING

Furnace heating has become more popular year by year. It has none of the disadvantages of stove heating, because the furnace plant is situated in the cellar close to the coal storage. In such a position it is out of the way, occupies the least valuable space in the house, and is so installed that the work of attendance may be reduced to a minimum.

The three principal systems of domestic furnace heating are: hot-air, hot-water, and steam. This classification is based on the medium used for transferring the heat derived from the burning fuel to those parts of the house where the heat is to be utilized. Of the three systems the first two are in more general use in Canada, the number of steam-heat installations being very small in comparison with the total number using either hot air or hot water. Therefore, for the purposes of this investigation no consideration was given to steam heating.

In general, hot-air heating is used in the smaller houses and hot-water heating in the larger ones. Unfortunately, no accurate information is available as to what proportion the numbers of one installation are to the other, but it is thought that the former outnumber the latter in the ratio of three to one. The situation, however, is largely governed by the relative first cost. Hot-air installations are as a rule found in the cheaper class of houses built to rent, while hot-water installations are found in the better class houses built to sell to home owners.

The comparative value of the three types of furnace heating systems is illustrated in Table II, which is the opinion of a well known authority on combustion. This table shows that the hot-water system is the best when all factors are considered, and it would be in the interest of fuel conservation were this system of heating given preference in future installations.

TABLE II[1]

Four Residence Heating Systems Compared

System	Comparative costs		Durability	Comfort
	Installation	Operation		
1. Hot air	50	100	50	60
2. Steam	85	85	90	80
3. Hot water	100	75	100	100
4. Vapour steam	90	75	90	100

[1]Table taken from "The Conservation of Fuel in the United States" by L. P. Breckenridge, United States Fuel Administration, 1918.

DISCUSSION ON HEATING TESTS IN GENERAL

DIFFICULTY OF MAKING RELIABLE TESTS

In making a series of tests of any kind, investigators usually follow a predetermined plan in the hope that concordant results will be obtained from which satisfactory deductions may be made. If many variable factors influence the tests, the difficulty of obtaining concordant results is increased unless the investigation is so planned that only one factor varies at a time and, unless previous experience has been had in planning and conducting the tests, difficulty may be encountered in obtaining the desired conditions.

Fuel tests are influenced by a number of factors, the chief of which are:–

1. Size, type, and design of equipment in which fuel is burned.
2. Kind, size, and quality of the fuel to be tested.
3. Mode of operating equipment, and plan adopted and followed in making the tests.

Therefore, as those familiar with such work will realize, it is often difficult to obtain concordant results from such tests, even when the tests are made

on a single fuel in one particular installation. When, therefore, the investigation is enlarged to include comparisons of various fuels when burned in all types of domestic heaters, the difficulties are greatly increased owing to the diversified equipment in general use, the operating conditions, and test methods.

In order to determine the relative value of various fuels actual tests should be made in some standard heating equipment, and, further, the fuels should all be tested in the same installation. There are so many standard types of domestic heaters in common use which vary greatly in size and design that it obviously would be impracticable to test the fuels in each different kind of heater. A choice must, therefore, be made of the particular heater best suited and most easily adapted to the tests, the assumption being that if all the tests were made in the same equipment, the results, as far as fuel comparisons are concerned, would hold relatively in the different classes of heaters.

To determine the relative values of various fuels for domestic heating it would be advisable to make all tests along lines similar to those on which the fuels are commonly used. Unfortunately, there is no common or set operating practice pertaining to all the different kinds of domestic heating equipment; the operating procedure followed varies greatly, different methods being followed for each different type and size of apparatus and in manners as different as are the temperaments of the individuals attending to the equipment.

In making comparative fuel tests, it is of the utmost importance to adopt and follow a set and predetermined plan and, in so far as possible, this plan should conform to accepted standard test methods. But, unfortunately, the only accepted standard test methods are those used for large-size commercial and power boiler equipment, and they do not give the same satisfactory results when used for small domestic heaters. Therefore it is not advisable that the procedure should strictly follow these methods, as the plan must be adapted to the usual household operating procedure as well.

FACTORS THAT INFLUENCE TESTS

The value of a fuel for domestic heating cannot be expressed in a single term for, when comparing the various fuels in an investigation of this kind, comparisons must be made not only of the efficiency of heat transference, but also of certain other factors which make the fuel particularly desirable for domestic purposes. A test to determine the efficiency of heat transference in domestic heaters will more or less be along lines similar to tests made in commercial or power boiler equipment for the same purpose. But, unfortunately, no one set of tests will serve to compare the fuels and arrange them in order of merit as to the other factors which go to make up the suitability of a fuel for domestic heating. A single series of tests should be run to grade the fuels as to each separate factor. Such a number of series was impossible in an investigation of this extent. Therefore only one series was made to determine the grading of the fuels as to efficiency of heat transference and which was to give only a general idea of the grading as to the other characteristics.

For an investigation of this kind it is desirable to report on the following factors:—

1. Efficiency, capacity, and cost—
   - *(a)* Efficiency of heat transference or overall thermal efficiency;
   - *(b)* Capacity—ability to deliver the amount of heat required over a sufficient length of time at the various combustion rates necessary;
   - *(c)* Cost per unit of heat delivered.
2. Control, regulation, and attendance—
   - *(a)* Control—rapidity of raising or lowering the heat of the house;
   - *(b)* Uniformity of regulation, i.e. the maintaining of a uniform temperature in the house;
   - *(c)* Total attendance needed.
3. Cleanliness—
   - *(a)* Dust and dirt in the cellar;
   - *(b)* Ash and clinker;
   - *(c)* Smoke and soot.
4. Handling and storage properties—
   - *(a)* Friability—breakage on handling;
   - *(b)* Disintegration—slacking in storage;
   - *(c)* Bulkiness—storage room required.

In commercial or power boiler work the efficiency of heat transference and the cost of the fuel per unit of evaporation are usually the most important factors, while control of fire, attendance, cleanliness, etc., are of secondary, if not minor, importance. The relative importance of these factors vary with the size and purpose for which the plant is used. All factors, however, are of less importance than that of high evaporative performance at minimum cost. For domestic heating, high efficiency in heat transference can be obtained only by proper and constant attention suitable to each installation, but such attendance is not feasible where the installation is small. Heaters for this service must be compact and of simple construction and not complicated by auxiliary attachments, so that those who are unskilled may operate the equipment with only intermittent attendance. For these reasons attendance may be of greater relative importance than efficiency of heat transference. In many installations the factors, amount of attention and the advantages of simple and easily operated and cared for equipment, are of prime importance and will more than offset the cost of burning a little more fuel. In other installations, ease of fire control with consequent rapidity of raising or lowering the temperature of the house, or uniformity of regulation—ability to maintain a uniform rate of heat output over a considerable length of time—may be of greater importance than to obtain the heat required at the lowest fuel cost. For house heating, the factors of regulation, ease of fire control, refuse and clinker formation, and their removal, fouling of the flue and chimney, creation of dust, dirt, smoke, soot, etc., are all important and must be considered as well as low fuel cost and efficiency of heat transference. The use of high priced fuels or the sacrifice of thermal efficiency may be justified on occasions when the relative importance of any one of the other factors becomes great.

It is almost impossible to arrange the factors which go to make up the general suitability of a fuel for domestic purposes in order of merit; in one installation one of the factors may outweigh the others, while in other installations the relative importance of the various factors may be reversed. It is quite evident that the importance of the various factors may vary widely according to the service to be rendered; and also that the other factors, other than fuel cost and efficiency of heat transference, are of greater relative value in house-heating installations than in commercial or power boiler work. Cleanliness, amount of attendance, and ease of fire control are of primary importance in the heating of small houses, whereas when domestic furnaces are used to heat large buildings such as apartment houses, offices, schools, etc., the conditions more nearly approach commercial or power boiler practice, where the cost of fuel and efficiency of heat transference are of first importance. When testing fuels in small house-heating boilers for the average conditions under which such boilers are operated, more difficulties are encountered than when conducting similar tests with larger apparatus. The low rate at which house-heating boilers are operated for either all or part of the time tends to make the results of different tests unsatisfactory for purposes of comparison, as it is almost impossible to conduct any two tests with any degree of uniformity, and apparently slight variations in the fire conditions have considerable influence on the results.

DIFFICULTY OF MEASURING FUEL CONSUMPTION

It is much more difficult to determine accurately the amount of fuel consumed in small domestic heaters than in commercial or power apparatus. The amount of fuel burned in a power boiler under test is many times greater than that burned during a test of equal length in a house-heating boiler, and, therefore, an error made in estimating the amount of unburned fuel at the start and finish of a test in the small boiler will be a very much greater percentage of the total fuel consumed than would be the case with the power boiler. This error is very noticeable when using the continuous fire or alternate method of starting and stopping boiler tests. The continuous fire or alternate method provides for the starting and ending of the test when the fire conditions are such that equal amounts of unconsumed combustible and ash are upon the grate at both times under consideration. Careful judgment and operation are required in this method. The fuel burned and the ash removed in the average power boiler test amount to many times the quantity of fuel and ash that may be upon the grate at the start and stop of the test, and a mistake, therefore, in judging the fire conditions at those times will make a comparatively small error in the final calculations. Small though this error may be it is always considered to be a measurable quantity even under the most favourable conditions when testing power boilers. When testing small domestic heating boilers, which, as a rule, have comparatively deep fuel beds, the quantity of fuel upon the grate at the beginning and end of a test is a very considerable proportion of the total fuel consumed, unless the test be of very long duration. The error expressed as a percentage of the total fuel consumed may be four or five times as great in the case of the house-heating boiler as in the case of the power boiler. There are two ways of meeting this diffi-

culty: first, to make tests very long, in which case the error becomes proportionately smaller as expressed in percentage of the total fuel fired; or second, by adopting another method of starting and stopping the tests.

METHODS OF STARTING AND STOPPING TESTS

Two methods are in general use for starting and stopping tests in small furnaces. Each method has its own peculiar advantages and each has its advocates.

In the new fire or dumping method a preliminary fire is made up and the boiler operated for some time until the boiler and equipment are thoroughly heated up in order that they may be in the same condition as during the test. Immediately before the start of the test the fire is dumped, all the refuse removed and a new fire quickly made with a known weight of wood, kindling, etc., before the conditions in the system have had time to alter; the commencement of the test is at the time of lighting the second fire. To end the test the fire is dumped and quenched, the residue is carefully removed, weighed and sent to the chemist for analysis and determination of the heat value and ash content.

In the continuous fire or alternate method a preliminary fire is made up as in the new fire or dumping method, and the boiler operated for at least one firing period as under test conditions. The fire is then cleaned and the fuel bed levelled. The thickness of the fuel bed and the extent to which it has been burned out are quickly estimated and noted. The test is then started by taking the initial observations. A weighed charge of fuel is then placed on the fire and the ash-pit thoroughly cleaned out. To end the test the fuel bed is cleaned as before and brought to the same condition as at the start, an endeavour is made to leave the same amount of unburnt fuel and ash on the grate, and then the final readings are taken, at which time the test ends. The ash-pit is immediately cleaned out, the contents are placed in covered cans, weighed and left to cool, after which the refuse is given to the chemist for analysis of the combustible content.

METHODS OF FIRING FUELS

There are two general methods of firing raw fuel in domestic furnaces. The usual method is that employed when burning anthracites and cokes, viz. to spread the raw fuel evenly and to a considerable depth over the grate. The other method is that used for burning soft coals and is more efficient than the first method for that purpose. The raw fuel is piled high on one side of the grate leaving red coals exposed on the other side, thereby affording a means of igniting the volatile gases as they are distilled from the freshly charged fuel. When it is necessary to add further fuel the raw coal is charged on the opposite side, the remains of the first charge remaining on the grate as glowing coals. A variation in this method is to spread the glowing coals of the fire evenly across the grate and to charge raw fuel in an annular ring, leaving a glowing spot in the centre. As the volatile gases are given off they are ignited by this hot spot and the burning fuel also has a tendency to fall in and fill up the hollow formed as the fuel is consumed in the centre.

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of the investigation was to obtain some measure of the comparative value of various coals when used for domestic heating. This was to be accomplished by comparing the behaviour of each fuel when burned in a standard type of domestic heater, with that of a typical sample of American anthracite coal. American anthracite was used as the standard for comparison on account of its almost universal use for domestic heating in Ontario and Quebec. Limitations of time and staff allowed only one series of tests to be made. Therefore, the comparison of the different fuels was based chiefly on the efficiency of useful heat transference, although some attention was also paid to such factors as: the attendance given the fire, ease of controlling rate of combustion, and cleanliness and the handling and storage properties of the fuel. These factors are all of importance, in gauging the general suitability of a fuel for domestic heating, but, obviously, no one series of tests could give a measure of all the factors and therefore the efficiency of useful heat transference is mainly stressed.

Inasmuch as all the tests were made in the same furnace and each in a similar manner, it was realized that the various fuels which differed widely in physical and chemical characteristics would give varying results, and in few cases would the best results be obtained for any one particular fuel. Therefore, the results obtained are only comparable when the fuels are burned in this type of furnace. Nevertheless, the results of the tests are a valuable indication of what results might be expected when other types of domestic heaters are used.

A number of tests were made on each fuel at three rates of combustion, when approximately 66,000, 99,000, and 132,000 B.T.U. per hour were delivered to the cooling water. Two tests were made at the 99,000 B.T.U. per hour rate, in order to check the operation of the duplicate apparatus. Unfortunately, the work could not be arranged so that all tests on one fuel could be made successively; a test on anthracite coal was made one week and during the next a test perhaps on coke or Alberta coal; also, some considerable time elapsed after the completion of a test before the reports of analyses were received and so the calculations could not be made until a considerable time after the tests had been completed. Therefore, it was made more difficult for the man in charge to maintain the accuracy and constancy of result desired between the various co-related tests, and although the tests were carefully made it was to be expected that some would be unreliable, but when such were found repeat tests were made. The Welsh, Scotch, smokeless semi-bituminous, and Alberta coals tested were all more or less friable; they broke up considerably on handling and disintegrated on storage, so that the coal as fired contained varying proportions of fines. Notwithstanding the many unfavourable features, the overall efficiency obtained for all the fuels tested was high and compared with the best efficiencies obtained in hand-fired boilers. The efficiencies obtained for co-related tests on the same fuel also agreed closely and were well within allowable experimental error.

Active test work extended over a period of about two years during which time twenty-one different fuels were tested at various loads. In all,

123 tests were made representing an aggregate of seventy weeks of actual testing. The tests were of variable length depending on a number of conditions that were decided on at the outset of the investigation, and also on restrictions that arose during the course of the work. In the main the length of the tests varied from 40 hours on fuels of low calorific value burned at high rates of combustion, to 120 hours on fuels of high calorific value burned at low rates of combustion; and in each case the duration was determined by the time required to burn 1,000 pounds of the fuel. Unfortunately, towards the end of the investigation it was found impossible, owing to a decrease in staff, to continue tests for more than 32 hours for the longest, and 16 hours for the shortest; during these tests only 250 to 300 pounds of fuel were consumed.

In order to distinguish between the standard tests where at least 1,000 pounds of fuel had been consumed and the shorter tests where only 250 to 300 pounds of fuel had been consumed, the former were termed "long tests" and the latter "short tests". Eighty-four of the tests were of long duration and thirty-nine were of short duration. The short tests, however, did not give the desired accuracy, and, further, in making such a long series of tests it was to be expected that some of the tests would not be representative of the fuels under consideration. Accordingly, forty-seven tests were disregarded in the discussion which follows, and the results, except where noted, were not included either in the charts or in the tables, other than Table VI. Of this number, thirty-four were short tests; in fact, the only short tests which were accepted were the ones on fuels where no long tests had been made.

The report consists mainly of a description of 123 tests made on 21 different fuels in a domestic furnace of the hot-water type. The tabulated and plotted results of these tests and the discussion of the results furnish the basis for this report.

PERSONNEL AND ACKNOWLEDGMENTS

The investigation was made under the direction of B. F. Haanel, Chief Engineer of the Division. The writers had direct supervision of the tests and were assisted by three observers. The following men served at various times in this capacity: A. W. Mantle, G. W. Read, R. A. Bolton, G. E. LeWorthy, H. McLeod, and C. S. Johnston.

All the chemical work in connexion with the sampling and analysing of the fuels and refuse was conducted under the supervision of R. E. Gilmore, Superintendent of the Chemical Laboratories of the Division.

G. W. Read, in addition to acting as senior observer during most of the tests, had charge of sampling the fuel and refuse, and also gave valuable aid in making the calculations required and in preparing some of the tables, charts, and diagrams.

THE FUELS TESTED

At the outset of the investigation the domestic fuels to be tested were to include only those which were readily obtainable on the Ontario and Quebec market; but at a later date, at the request of the Dominion Fuel Board, the scope of the work was enlarged to include representative samples of Alberta coal; air-dried, machine peat produced in the Government experimental plant at Alfred, Ontario; and coke made from Nova Scotia coal. In securing the coals for test purposes, an effort was made to secure samples that would be truly representative of each type of fuel, and the samples secured were what the general public might expect to receive.

In all, twenty-one different fuels were tested, of which eight were purchased from coal dealers in Ottawa. These comprised: three anthracites, two cokes, two smokeless semi-bituminous coals, and air-dried, machine peat. Of the remaining thirteen, nine were obtained from Alberta, and were selected by the late Dr. D. B. Dowling of the Geological Survey and Dominion Fuel Board, with the co-operation of the Scientific and Industrial Research Council of Alberta; two cokes were obtained from Nova Scotia, one coke was obtained from the United States, and the Welsh briquettes were obtained from Montreal. Table III lists the twenty-one fuels that were tested and also states where they were obtained, the trade size under which they were sold, the quantity received, the number of tests made, and also the date the coals were received in storage.

COMPARISON OF THE FUELS TESTED

As previously stated, twenty-one different solid fuels were tested. Table IV gives the analyses and fuel ratios of the various fuels; general information, with the principal physical and burning characteristics of each fuel, is given in Table V.

TABLE III

List of Fuels Tested

No.	Fuel	Obtained from	Trade size	Quantity received, tons	Number of tests made	Date received
1	American anthracite	Ottawa coal dealer	Stove	....	15	1924
2	Welsh anthracite	Ottawa coal dealer	Re-screened	6	6	1924
3	Scotch semi-anthracite	Ottawa coal dealer	Re-screened	5	4	1924
4	Gas coke	A Canadian gas company; made from American coal	Crushed	....	8	1924
5	By-product coke No. 1	Imported from United States	Egg	3	2	1924
6	By-product coke No. 2	A Canadian by-product coke oven; made from American coal	Stove	5	6	1925
7	By-product coke No. 3	A Canadian by-product coke oven; made from Canadian coal	Small	4	5	May, 1925
8	By-product coke No. 4	A Canadian by-product coke oven; made from Canadian coal	Medium	1¼	3	Oct., 1925
9	American smokeless, semi-bituminous No. 1	Ottawa coal dealer	Smokeless, forked lump	5	9	Oct. 15, 1924
10	American smokeless, semi-bituminous No. 2	Ottawa coal dealer	Smokeless, egg	3	4	April 24, 1925
11	Alberta semi-bituminous	The mine	Smokeless	10	9	Dec. 17, 1924
12	Alberta sub-bituminous No. 1	The mine	Egg	10	6	Jan. 8, 1925
13	Alberta sub-bituminous No. 2	The mine	Stove	7½	9	Feb. 2, 1925
14	Alberta sub-bituminous No. 3	The mine	Stove	10	6	Dec. 11, 1924
15	Alberta domestic No. 1	Alberta coal dealer	Stove and nut	12	4	Dec. 11, 1924
16	Alberta domestic No. 2	The mine	Lump	6	6	June 4, 1924
17	Alberta domestic No. 3	The mine	....	6	7	May 19, 1924
18	Alberta domestic No. 4	Alberta coal dealer	Egg	6	4	May 22, 1924.
19	Alberta domestic No. 5	The mine	Stove	6	7	May 21, 1924
20	Welsh briquettes	Montreal coal dealer	Ovoids	1,700 lb.	1	Feb., 1924
21	Air-dried, machine peat	Ottawa coal dealer	Peat	2,500 lb.	2	Oct. 16, 1925

TABLE IV

Range in Proximate and Ultimate Analyses, Fuel Ratios, and Calorific Values of the Fuels Tested

	Fuel	Range in proximate analysis as fired				Range in ultimate analysis as fired						Range in fuel ratio	Range in calorific value, B.T.U. per lb. as fired
		Water %	Ash %	Volatile matter %	Fixed carbon %	C %	H %	Ash %	S %	N %	O %		
1	American anthracite	1·8 4·0	11·6 15·7	5·5 6·5	74·7 79·1	76·1 78·5	2·4 3·1	11·6 14·6	0·7 1·0	0·8 0·9	4·5 5·2	11·65 14·38	11,990 12,760
2	Welsh anthracite	1·8 2·7	4·2 5·3	7·6 8·3	84·8 85·3	...... 85·9	...... 3·3	...... 5·3	0·9 1·2	...... 1·0	...... 3·3	10·90 12·69	13,930 14,260
3	Scotch semi-anthracite	2·9 3·0	6·8 7·1	.... 10·0	80·0 80·2	82·3 82·5	...... 3·6	6·8 7·1	...... 0·7	...... 1·8	4·5 4·6	8·0 8·05	13,760 13,780
4	Gas coke	0·2 1·0	11·3 13·1	.... 1·9	84·2 85·8	83·2 84·5	...... 0·6	11·3 13·0	1·0 1·1	...... 1·1	0·8 1·4	....	11,955 12,250
5	By product coke No. 1	0·5 0·9	7·4 8·5	1·7 2·1	89·3 90·0	86·9 87·7	...... 0·8	7·4 8·5	...... 0·7	...... 0·8	2·3 2·7	....	12,940 13,040
6	By-product coke No. 2	0·1 0·6	12·6 13·4	1·6 1·8	84·7 85·2	....	....	....	...... 1·9	....	....	....	11,880 11,980
7	By-product coke No. 3	0·5 0·8	6·9 8·2	1·4 1·7	89·4 90·8	87·8 89·2	...... 0·6	6·9 8·2	...... 1·7	...... 0·9	0·6 0·8	....	12,900 13,100
8	By-product coke No. 4	0·5 0·8	6·8 7·1	1·1 1·8	90·3 91·6	88·6 89·1	...... 0·7	6·8 7·1	1·5 1·6	....	....	....	12,960 13,120
9	American smokeless, semi-bituminous No. 1	0·8 1·3	8·1 9·0	19·2 20·1	70·2 71·3	80·0 81·0	...... 4·5	8·1 9·0	2·7 3·2	1·3 1·4	2·2 2·7	3·50 3·70	13,930 14,180
10	American smokeless, semi-bituminous No. 2	0·6 1·0	11·4 10·0	15·6 16·0	72·0 73·4	78·8 80·3	...... 4·3	10·0 11·4	1·7 1·8	...... 1·2	2·4 2·6	.... 4·60	13,750 14,020
11	Alberta semi-bituminous	0·7 1·0	9·1 13·4	15·7 16·4	70·0 74·0	77·7 81·4	4·1 4·3	9·1 13·4	0·7 0·8	1·3 1·4	2·6 3·0	4·25 4·65	13,260 13,940
12	Alberta sub-bituminous No. 1	8·0 9·7	6·9 8·0	32·2 34·6	50·1 51·3	65·4 67·5	5·0 5·1	6·9 8·0	...... 0·3	...... 1·0	19·1 20·2	1·45 1·55	11,110 11,690

13	Alberta sub-bituminous No. 2	7·3	9·3	34·1	46·8	63·0	5·0	9·3	......	......	19·7	1·35	10,740
		8·9	10·3	35·7	47·8	64·6	5·1	10·3	0·2	0·8	20·9	1·39	11,100
14	Alberta sub-bituminous No. 3	9·7	9·4	32·7	45·2	61·6	......	9·4	0·6	......	20·0	1·25	10,820
		10·3	10·7	35·7	46·7	62·8	5·5	10·7	0·7	1·6	20·3	1·45	11,140
15	Alberta domestic No. 1	18·7	7·5	30·1	43·2	56·6	......	7·5	......	......	......	....	9,390
		18·8	7·9	30·2	43·6	57·0	5·8	7·9	0·4	1·2	28·1	1·45	9,390
16	Alberta domestic No. 2	12·5	12·3	31·8	41·1	55·4	5·3	12·3	1·1	......	23·8	1·25	9,600
		13·2	12·7	33·2	42·9	55·7	5·4	12·7	1·2	1·3	24·3	1·35	9,720
17	Alberta domestic No. 3	15·1	7·2	30·9	43·8	54·6	5·5	7·2	......	......	28·9	1·30	9,470
		16·7	8·8	33·4	44·7	56·2	5·7	8·8	0·5	1·2	30·1	1·43	9,990
18	Alberta domestic No. 4	15·8	11·3	28·2	43·5	53·9	......	11·3	......	......	27·6	....	8,960
		15·9	12·4	28·7	44·2	54·8	5·1	12·4	0·2	0·8	27·8	1·54	9,110
19	Alberta domestic No. 5	17·3	7·9	31·5	39·8	51·6	5·5	7·9	0·2	......	30·8	1·25	8,700
		19·6	9·7	32·2	40·9	52·8	5·7	9·7	0·3	1·0	32·4	1·30	9,020
20	Welsh briquettes	1·3	10·2	12·4	76·1	......	......	......	1·0	......	......	....	13,380
21	Air-dried, machine peat	25·1	4·3	43·1	20·6	38·7	7·0	4·3	0·1	1·1	44·4	0·48	6,630
		32·0	4·4	47·0	23·5	42·8	7·4	4·4	0·2	1·2	48·4	0·50	7,350

TABLE

Screen Analyses and General

—	Fuel	Trade size	Screen Analysis[2] as received in storage					
			Lump %	Egg %	Stove %	Nut %	Pea %	Fines %
1	American anthracite.............	Stove	nil	6·9 13·7	61·4 69·4	14·5 26·0	1·2 2·5	1·2 1·6
2	Welsh anthracite................	Re-screened	2·9	21·5	32·6	31·6	3·1	8·3
3	Scotch semi-anthracite..........	Re-screened	nil	4·8	22·1	29·7	20·2	23·2
4	Gas coke........................	Crushed	nil	nil	39·2	44·9	11·2	4·7
5	By-product coke No. 1...........	Egg	....	.....	....	.....	.....	.....
6	By-product coke No. 2...........	Stove	nil	28·6	58·0	11·7	0·7	1·0
7	By-product coke No. 3...........	Small	nil	nil	7·8	50·2	30·8	11·2
8	By-product coke No. 4...........	Medium	nil	1·3	61·8	34·7	1·3	0·9
9	American smokeless, semi-bituminous No. 1	Smokeless, forked lump	nil	10·7	13·2	16·1	10·6	49·4
10	American smokeless, semi-bituminous No. 2	Smokeless, egg	7·6	12·7	15·7	10·5	6·2	47·3
11	Alberta semi-bituminous.........	Smokeless	13·7	12·2	13·8	18·5	8·9	32·9
12	Alberta sub-bituminous No. 1.....	Egg	14·6	33·2	22·7	12·6	5·2	11·7
13	Alberta sub-bituminous No. 2.....	Stove	nil	24·7	50·8	18·6	2·6	3·3

V[1]

Characteristics of the Fuels as Tested

General Characteristics

Apparent specific gravity[3]	Lb. per cubic foot[4]	Cubic feet per ton[5]	Handling qualities	Storage qualities	Coking qualities	General performance[6]
1·56	55·2	36	Excellent	Excellent	Non-coking	Good; no attention required; no clinkering but large amount of refuse; smokeless.
1·36	51·8	39	Good	Good	Non-coking	Excellent; no attention required; very little clinkering and refuse; smokeless.
1·35	52·8	38	Good	Good	Non-coking	Excellent; no attention required; little clinkering and refuse; smokeless.
0·82	25·8	78	Good	Very good but very bulky	....	Good; some attention required; considerable refuse and some clinkering; smokeless.
....	....	....	Very good	Very good but quite bulky	....	Good; some attention required; large amount of refuse and some clinkering at high loads; smokeless.
0·90	28·7	70	Very good	Very good but quite bulky	....	Good; little attention required—little clinkering and refuse; smokeless.
....	....	....	Very good	Very good but quite bulky	....	Good; little attention required; little refuse but some clinkering; smokeless.
0·86	....	....	Very good	Very good but quite bulky	....	Good; little attention required; little clinkering and refuse; smokeless.
1·35	51·8	39	Fair	Fair	Strongly coking	Fair; considerable attention; little refuse and some clinkering; considerable smoke when first fired.
....	....	....	Fair	Fair	Strongly coking	Fair; considerable attention; little refuse and some clinkering; considerable smoke when first fired.
1·34	56·3	36	Fair	Fair	Slightly coking	Fair; considerable attention; some refuse and considerable clinkering; some smoke when first fired.
1·35	49·2	41	Good	Fair	Non-coking	Fair to good; some attention; little refuse; considerable clinkering; yellowish smoke.
1·35	....	....	Good	Fair	Non-coking	Fair to good; some attention; moderate refuse; considerable clinkering; yellowish smoke.

TABLE

Screen Analyses and General

—	Fuel	Trade size	Screen Analysis[2] as received in storage					
			Lump %	Egg %	Stove %	Nut %	Pea %	Fines %
14	Alberta sub-bituminous No. 3.....	Stove	nil	10·4	34·4	41·8	8·6	4·8
15	Alberta domestic No. 1...........	Stove and nut	nil	4·3	26·7	41·1	14·6	13·3
16	Alberta domestic No. 2...........	Lump	14·1	28·5	20·0	16·0	7·5	13·9
17	Alberta domestic No. 3...........	....	3·4	36·4	27·0	17·4	6·4	7·4
18	Alberta domestic No. 4...........	Egg	4·3	34·4	31·9	15·0	5·6	8·8
19	Alberta domestic No. 5...........	Stove	0·9	23·2	20·4	20·2	11·4	23·9
20	Welsh briquettes.................	Ovoids	....	......	....	......	......	......
21	Air-dried, machine peat..........	Peat	37·0	23·5	15·9	13·3	3·7	6·6

[1]Prepared by the Division of Fuels and Fuel Testing.

[2]Square screens:—lump, on 3″; egg, through 3″ on 2″; stove, through 2″ on 1½″; nut, through 1½″ on ¾″; pea, through ¾″ on ½″; fines, through ½″.

[3]Determined according to standard method A.S.T.M.—D 167—24.

[4]Determined in 13·6 cu. ft. box, 1′ 10″ by 2′ 6″ by 2′ 11¾″ deep.

[5]One ton of 2,000 pounds.

[6]When fired in standard domestic hot-water boiler designed for burning anthracite.

V[1]—Concluded

Characteristics of the Fuels as Tested—Concluded

General Characteristics

Apparent specific gravity[3]	Lb. per cubic foot[4]	Cubic feet per ton[5]	Handling qualities	Storage qualities	Coking qualities	General performance[6]
1·35	49·4	41	Good	Fair	Non-coking	Fair to good; some attention; moderate refuse; large amount of clinkering; yellowish smoke.
1·27	50·4	40	Good	Fair	Non-coking	Fair to good; some attention; little refuse; considerable clinkering; whitish smoke.
1·35	54·4	37	Good	Fair	Non-coking	Fair to good; some attention; considerable refuse and clinkering; yellowish smoke.
1·31	....	....	Good	Fair	Non-coking	Fair to good; some attention; little refuse and considerable clinkering; white smoke.
1·31	51·1	39	Good	Fair	Non-coking	Fair to good; some attention; moderate refuse and clinkering; little whitish smoke.
1·27	....	....	Fair	Poor	Non-coking	Poor; considerable attention; little refuse and clinkering; little whitish smoke.
....	....	....	Good	Good	Non-coking	Good; no attention; considerable refuse; no clinkering; smoky when first fired.
0·92	....	....	Fair	Fair but bulky	Non-coking	Poor; great deal of attention; very little refuse; no clinkering; considerable smoke.

TYPE OF DOMESTIC HEATER USED FOR THE INVESTIGATION

Inasmuch as the conditions obtaining in actual practice of necessity had to be approximated in making these tests, the various types of domestic heaters in common use were considered before deciding on the particular type to employ. It was finally decided that the purpose of the investigation would best be served by making the tests in either the hot-air or hot-water type of heater, as both types are used extensively throughout Ontario and Quebec. While it would have been desirable to have made the comparative burning tests in both types of heater, this was not feasible at that time. Of the two types, the hot-water heater was the more readily adaptable for the investigation because of the ease with which the heat delivered by the burning fuel to the water could be measured. Moreover, to adapt the hot-air furnace to such an investigation would require a larger and more complex layout of apparatus, and the difficulty of obtaining reliable results would be greatly increased. Accordingly, a domestic furnace of the hot-water type, of a size suitable to heat a house of eight or nine rooms, was chosen, in which all tests were made, each fuel being tested in turn in the same installation. It was thought that in all probability the relationship of the compared fuels as determined by the tests would be fairly constant if the same fuels were used in a hot-air heater, and at least the results obtained would prove a valuable indication of what the results would be had other commonly used types of domestic heaters been used.

DESCRIPTION OF THE EXPERIMENTAL HEATING PLANT

The heating plant used for this investigation consisted of a round hot-water boiler; a radiation tank and cooling-water system; and the usual equipment of scales for weighing fuel and refuse; thermometers; pyrometers; draught gauges, gas-sampling apparatus; gas-analysis apparatus; and water-meter calibration apparatus, consisting of tanks, weigh scales and piping. Figure 1 shows the general arrangement of the equipment, piping, etc.

THE FURNACE

The round hot-water boiler used in the investigation was of standard design, similar in all respects to such as are installed in an average size house of eight or nine rooms. The boiler consisted of a number of separate castings set in cement and bolted together. The base casting, which formed the ash-pit of the furnace, was $15\frac{1}{2}$ inches high and held seven triangular-shaped, revolving grate bars. These bars were so geared together that the grate was shaken in three sections. The fire-pot casting, $21\frac{3}{4}$ inches high, rested on the base casting and was slightly smaller at the bottom than at the top. It was water-jacketed and the inner surface slightly overhung the grate. The fire-pot casting supported four water-section castings, each being approximately $2\frac{3}{4}$ inches thick, which were pierced by ports, arranged in such a manner that the products of combustion took a

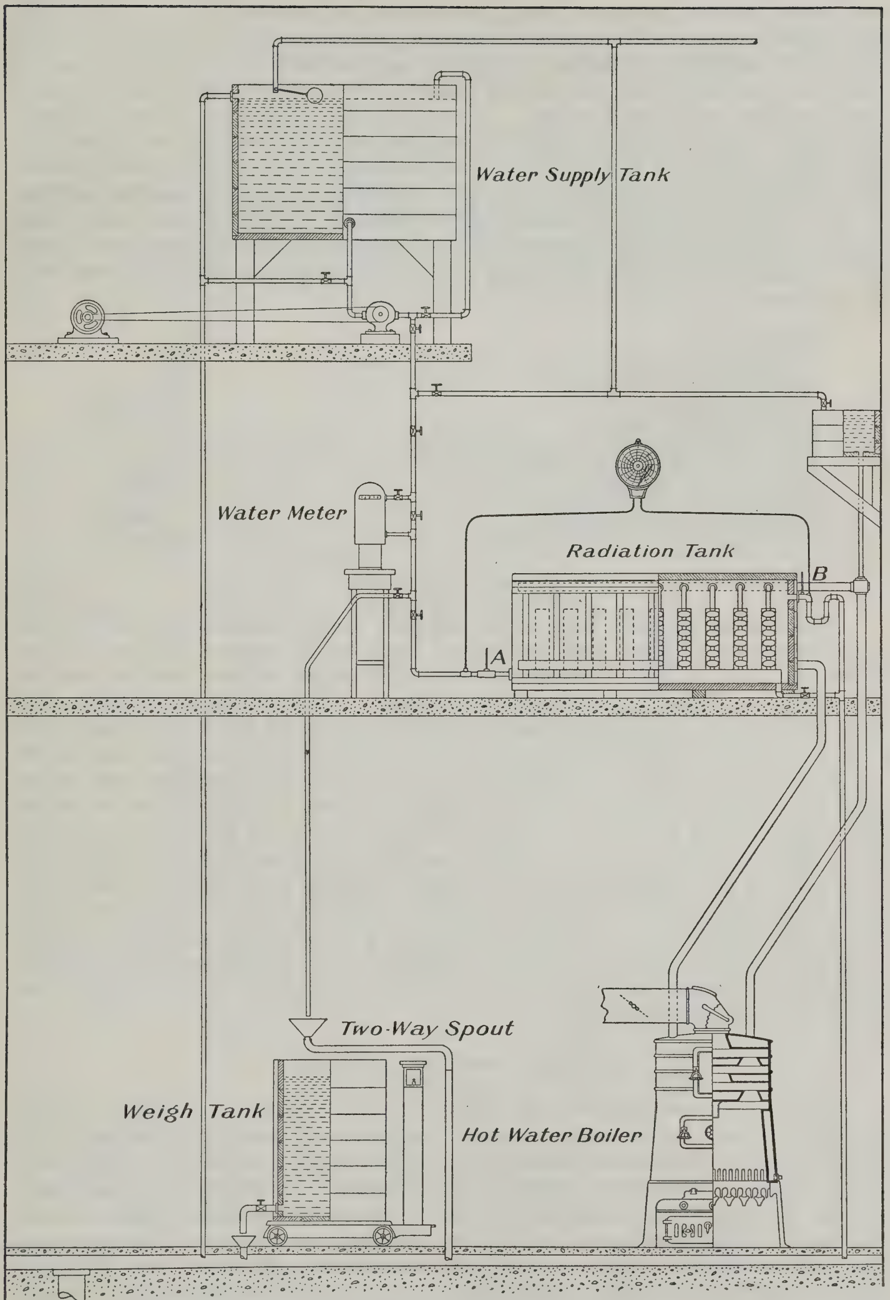


Figure 1.—Elevation showing layout of apparatus used for domestic heater fuel tests.

staggered path in passing from the fire-pot up through the ports to the flue. The top section, however, forming the cap of the furnace, had only one port, centrally located, to which a patented fixture was attached containing a check damper. This fixture served as the connexion between the flue pipe and the furnace. The flue pipe, which extended approximately 35 feet upward through the roof of the test room, formed the stack, and was made up of 8-inch galvanized iron pipe. The water sections and the water-jacketed part of the fire-pot casting made up the heating surface of the furnace which totalled approximately 32·4 square feet. The nominal diameter of the grate was 25 inches, giving a nominal grate area of 3·4 square feet. The following are the main ratings and dimensions of the furnace:—

Size of boiler	No. 4
Net rating, feet of radiation	670
Gross rating, feet of radiation	1,100
Nominal diameter of grate	25 inches
Nominal grate area	3·4 square ft.
Area of heating surface	32·4 "
Ratio of heating surface to grate area	9·2
Total volume of fuel and combustion space	5·4 cubic ft.
Diameter of smoke outlet	8 inches
Number of circulating-water openings	4
Size of circulating-water openings	2 inch dia.
Total approximate weight of castings	1,630 pounds

RADIATION TANK

The radiation tank was a box, 6½ feet long, 3 feet wide, and 2½ feet deep, containing nine wall radiators, each of 9 square feet radiation. These radiators were connected to 2½-inch flow and return headers, one on either side and running the length of the tank. The headers were connected by 2-inch piping to the circulating-water system of the boiler, and both headers and piping were thoroughly insulated. Inside the tank the radiators were placed side by side and connected in parallel between these headers. The inlets from the flow header entered the top of the radiators while the outlets to the return header were taken off at the bottom. A valve was placed in the inlet to each radiator, in order that any one might be cut out of the circuit as desired. The tank was built of 1½-inch lumber, lined with copper sheeting and thoroughly insulated on all sides. The insulation consisted of ¼-inch air space, ⅛-inch sheet asbestos, rigidly nailed on furring strips of ordinary lath, and over all a ½-inch thickness of sheet felt. The top of the tank was made removable to allow of inspection of the radiators at intervals.

COOLING-WATER SYSTEM

The heat was carried away from the circulating-water system of the furnace by means of cooling water which flowed past and between the radiators in the radiation tank. The cooling water was admitted through a 1-inch pipe at the bottom of one end of the tank and left through a 1½-inch pipe at the top of the other end. The inlet pipe was fitted with a short length of rubber tubing in which was inserted a mercury thermometer. The rubber tubing, being a good non-conductor of heat, was used to prevent heat from passing from the hot water in the radiation tank along the iron inlet pipe to the bulb of the thermometer. The outlet pipe was so

situated with respect to the height of the radiators that at all times they were completely immersed in the cooling water. This pipe was trapped close to the tank to prevent siphoning and to immerse completely the bulb of another mercury thermometer similar to the one in the inlet pipe.

In order to ensure a steady and constant flow of cooling water, a small rotary pump, electrically driven, was installed, which drew the water from a storage or supply tank and forced it through the meter and thence to the inlet pipe of the radiation tank. The supply tank, in which the water level was kept constant by means of a ball and cock valve on a pipe from the city water supply main, was placed on a floor 7 feet above the radiation tank, and had a capacity of some 200 gallons.

WATER METER

An accurate measure of the quantity of water flowing through the radiation tank was absolutely essential in the method employed for measuring the heat given up by the furnace; to secure this a piston type meter was selected. A one-half inch meter having a full flow capacity of 25 gallons per minute was installed, with the manufacturer's guarantee that the error would not be greater than 1 per cent for all water flows from a dribble to full capacity. This meter was calibrated in Imperial gallons and could be accurately read to within one gallon.

WATER-METER CALIBRATION SYSTEM

To ensure accuracy in the measurement of the water, the meter was calibrated before and after each test; and to accomplish this, the cooling-water pipes were so arranged with valves that the radiation tank could be by-passed as desired. When this was done the cooling water from the meter passed down to a two-way movable spout and thence either directly to the drain or into a tank placed on scales; this tank had a capacity of 500 pounds of water. The first step taken in calibrating the meter was to by-pass the radiation tank and set the valve from the supply tank so that the same quantity of water per minute, which was to be or had been used during the test, would pass through the meter, the two-way spout being thrown so that the water passed into the drain. The tare of the weigh tank was taken, and after a constant water flow was observed through the meter, the two-way spout was switched to throw the water into the weigh tank, and at the same instant the meter was read. After fifty gallons had passed through the meter the spout was again switched. The tank was then weighed, and in this manner the error in the meter was at once observed. These meter tests were continued until the error became constant. Throughout the investigation the error seldom exceeded 2 per cent and averaged a little over 1 per cent; the greatest errors were due to the wear in one of the valves. However, this was adjusted from time to time to take up this wear. The cooling-water system proved to be very satisfactory and very constant flows of water were maintained during the tests, with variations in flow of seldom more than 1 gallon from one half-hour period to another.

MISCELLANEOUS APPARATUS

The thermometers used to measure the temperature of the cooling water were calibrated to one-tenth of 1 degree, in the Surveys Laboratory of the Department of the Interior. The scale of these thermometers was from 32° to 200° F. and was graduated in single degrees. A double-pen recording thermograph gave a continuous record of the inlet and outlet temperatures of the cooling water, the bulbs of which were placed in the cooling water in close proximity to the mercury thermometers.

Two mercury thermometers, graduated for 2-degree readings, scale 32° to 220° F., were used to measure the temperature in the circulating water of the furnace, the bulb of one being immersed in the flow side of the furnace, and the other in the return side.

The temperature of the flue gases at the offtake from the furnace was measured by means of a pyrometer. This pyrometer was calibrated from time to time by means of the melting points of various metals.

The draught or pressure in the flue pipe was obtained by means of a draught gauge reading to within 1 one-hundreth of an inch of water.

The flue gas was sampled continuously, the sample being taken off at the end of each hour and analysed in a Hayes-Orsat apparatus.

DUPLICATION OF APPARATUS

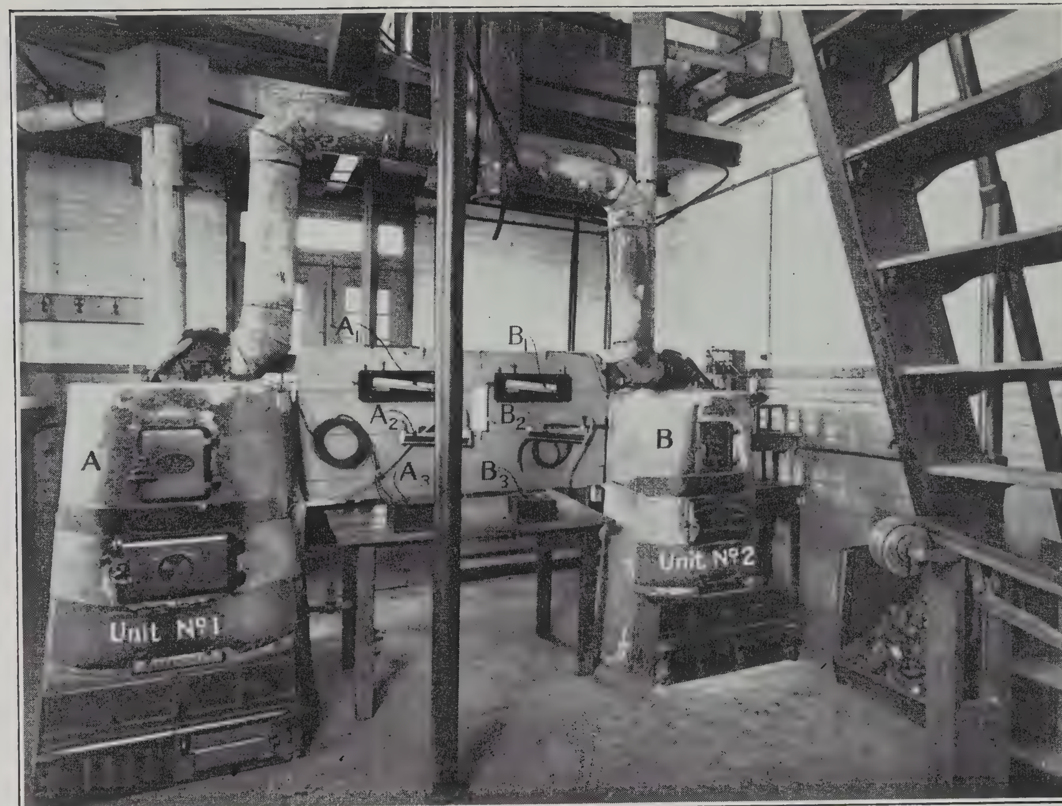
In order to hasten the completion of the investigation, another furnace, radiation tank, water meter, thermograph, etc., were set up and operated together with the first system. The duplication of plant enabled the investigators to check their work by operating the two furnaces at the same load and at the same rate of burning, and, in addition, by operating one furnace at high load while the other was being operated at low load, permitted a reduction in the time of the investigation to two-thirds of that required had a single furnace been employed.

METHOD OF CONDUCTING TESTS

MEASUREMENT OF HEAT TRANSFERENCE

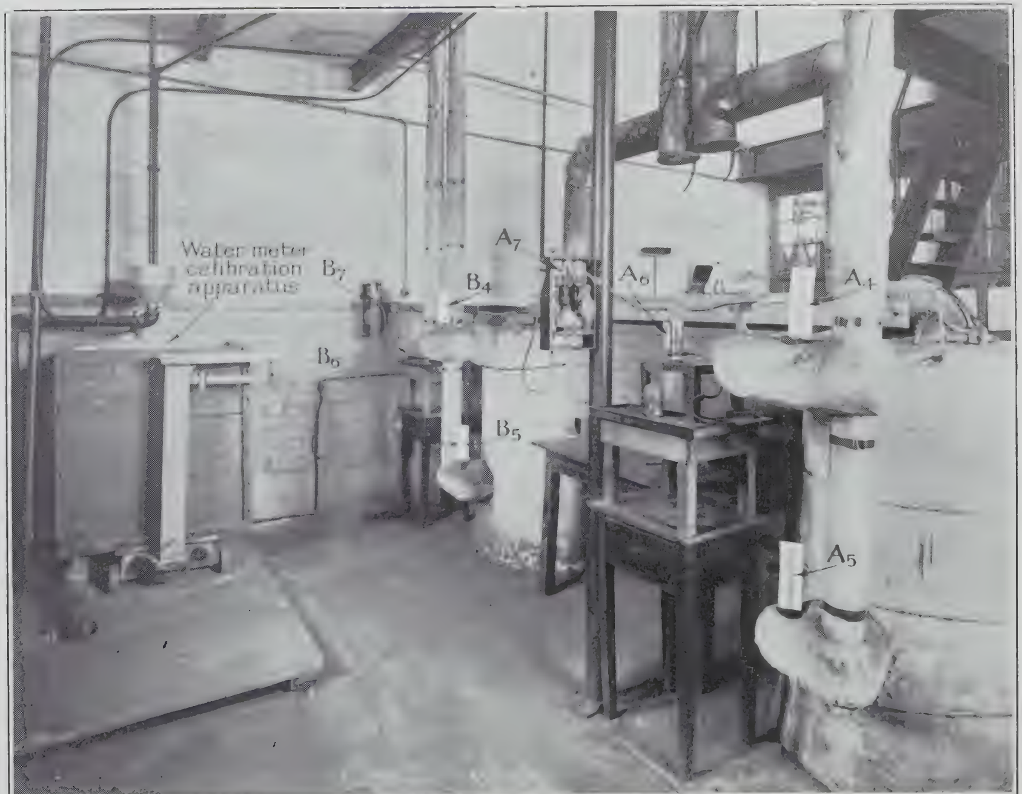
There are two commonly accepted methods that might have been used for measuring the useful heat output of the hot-water boiler. In the one method, a known weight of cold water is forced through the boiler and its rise in temperature measured by means of thermometers placed at the inlet and outlet, whence by simple calculation a measure of the heat delivered to the circulating water may be obtained. This method is only fairly accurate because the water circulating through the furnace is quite cold at the inlet and therefore receives heat at a faster rate than when it is sent through the circulating system by the force exerted by the difference in specific gravity between the hot water on the flow side and the cooler water on the return side.

In the other method, which may be termed a calorimetric one, a closed circulating system having a definite quantity of cast-iron radiating surface is coupled to the flow and return sides of the boiler. The radiating



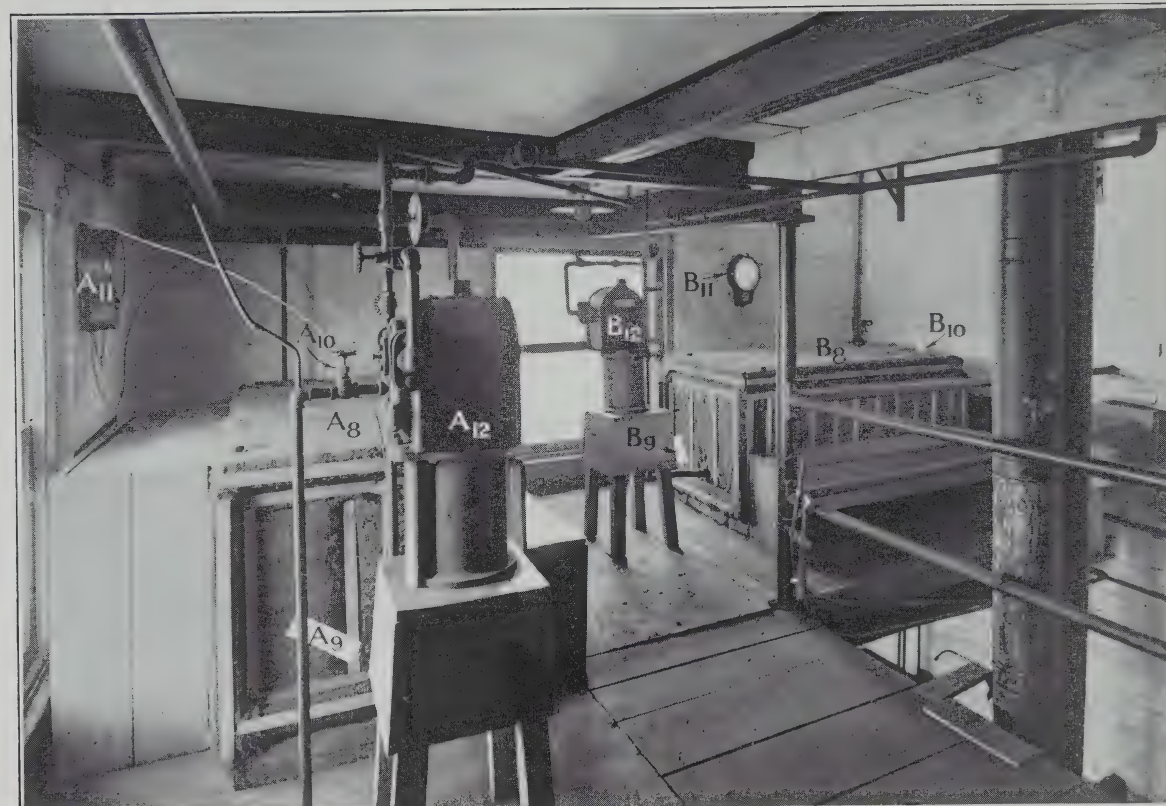
Front view of domestic furnace installation.

A—B. Domestic hot-water boilers, Units No. 1 and No. 2.
A_1—B_1. Draught gauges measuring flue draughts.
A_2—B_2. Draught gauges measuring fire-box draughts.
A_3—B_3. Pyrometers measuring flue-gas temperatures.



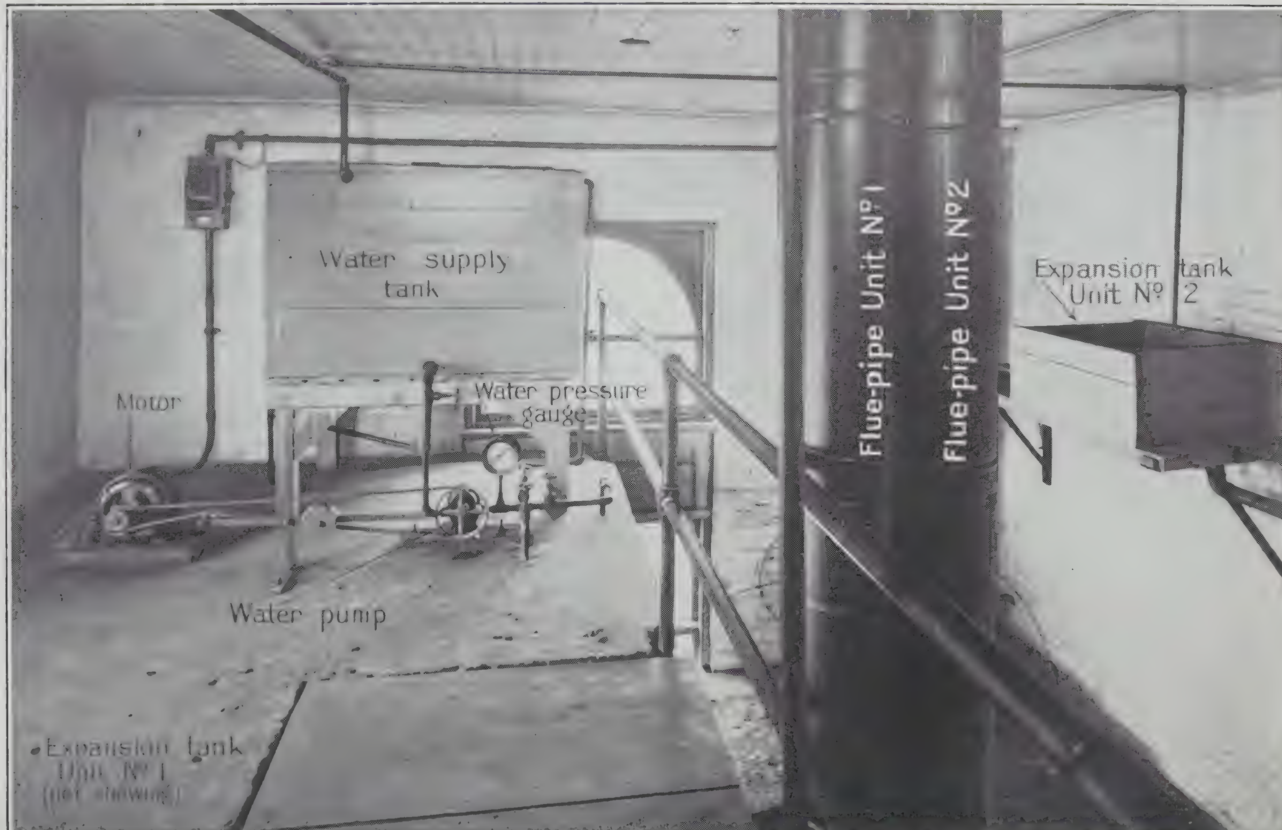
Rear view of domestic furnace installation.

A_4—B_4. Thermometers measuring flow circulating-water temperatures.
A_5—B_5. Thermometers measuring return circulating-water temperatures.
A_6—B_6. Flue-gas sampling apparatus.
A_7—B_7. Orsats for analysing flue gases.



General view of second floor level.

A_8—B_8. Radiation tanks.
A_9—B_9. Thermometers measuring inlet cooling-water temperatures.
A_{10}—B_{10}. Thermometers measuring outlet cooling-water temperatures.
A_{11}—B_{11}. Double pen thermographs recording inlet and outlet cooling-water temperatures.
A_{12}—B_{12}. Water meters measuring cooling water.



General view of third floor level, showing water supply system and expansion tanks.

surface is contained in a tank through which cooling water passes continuously. The weight of cooling water passing over and by the radiating surface is measured, as well as its temperature rise, whence by simple calculation, the amount of useful heat given up by the boiler may be determined. As this method more nearly approaches conditions which pertain to household installations, it was considered the more accurate method of the two and was, therefore, adopted for this investigation.

The circulating system, which was coupled to the flow and return sides of the boiler, contained 81 square feet of cast-iron radiation surface placed within an insulated copper-lined box which was situated on a floor $10\frac{1}{2}$ feet above the furnace floor. Cooling water entered the box at the bottom of one end and overflowed through a large pipe at the top of the other end, in such a manner that the radiators were always totally immersed. A piston or displacement type of water meter, which was calibrated before and after each test to determine its accuracy, was placed on the inlet side of the cooling-water system and measured the quantity of cooling water passed through the box. The temperature rise of this cooling water as it flowed through the box was measured by means of calibrated thermometers placed in the inlet and outlet cooling-water lines close to the box (*see* points A & B, Figure 1), and these temperatures were also recorded by a double-pen thermograph, the bulbs of which were placed at the same two points.

STARTING AND STOPPING THE TESTS

Tests may be started and stopped by either one of two generally accepted methods, known respectively as the new-fire and continuous-fire methods. The new-fire method of starting and stopping tests is recommended by the American Society of Heating and Ventilating Engineers for tests made in small heating boilers where the fuel used is anthracite, but for tests using other fuels, the continuous-fire method is recommended. Inasmuch as it was desirable to use one method for all tests and as the great majority of the fuels were other than anthracite and the furnace was not particularly adapted for the use of the new-fire method, the continuous-fire method of starting and stopping the tests was used throughout the investigation, and was as follows:—

A fire was built in the furnace the evening before the start of the test, and the furnace was then operated for a period of at least twelve hours at the rate which would pertain during the test, thus endeavouring to ensure that the system would be thoroughly heated up and that the fuel bed would be in a more or less stable condition similar to what it would be during the test. Before starting the test the fire was burned down to a pre-determined level; then just before the beginning the grates were carefully shaken, the fuel bed was well cleaned and the remaining live fuel was raked evenly over the grate and constituted the foundation for the first fuel charge. The thickness of the fuel bed, its level and general condition were noted and recorded, and the test was started at the time of making these observations. The first charge of fuel was then fired, the ash-pit was immediately swept free of all ash and refuse which was discarded, and the test then proceeded.

To terminate the test the fire was brought as nearly as possible to the same condition as that which pertained at the beginning. The fire was allowed to burn down, the grates were shaken, and the fuel bed was cleaned so as to leave the same amount of live fuel on the grate as at the start, and the test was stopped at the time when this condition was reached. The contents of the ash-pit were removed immediately, placed in covered ash cans, weighed, and, along with the other refuse removed during the test, was sent to the chemical laboratories for analysis.

FIRING METHODS

A variety of fuels, which differed widely in chemical, physical, and burning properties, were tested and obviously it was advantageous to use different methods in firing them. The methods used were such as to suit the physical characteristics of three groups of fuels, viz., anthracites and cokes; semi-bituminous coals; and Alberta sub-bituminous and domestic coals. A description of the methods used is as follows:—

Before charging the anthracites and cokes the fire was well shaken; the quantity of fuel required for the fire period was then charged into the fire-pot completely covering the incandescent fuel bed. When the fuel was as bulky as coke, it was practically necessary to fill the whole combustion space, in order to charge the requisite weight of fuel into the furnace. With the anthracites, however, it was only necessary to crown the fuel bed a little above the level of the bottom of the fire-door.

With the semi-bituminous coals it was found to be advantageous to leave a part of the glowing fuel bed uncovered, in order to ignite the volatile gases as they were given off from the freshly charged fuel, and to heap the fresh charge to either one side or other of the grate; or to heap fresh fuel around the circumference of the fire-pot and leave the centre of the hot fuel bed exposed to ignite the gases.

When testing Alberta sub-bituminous and domestic coals an endeavour was made to follow as closely as possible the method of firing advocated by the Fuel Engineer of the Province of Alberta, viz., to pack the fresh fuel as closely as possible on one side of the fuel bed, placing the larger lumps at the bottom, to form a bridge wall across the fire-pot from the front to rear, and finally covering the charge with the fines. For the next period fuel was fired on the opposite side of the fuel bed. Each time glowing fuel was left on one half of the grate. The fire-pot and combustion space were not well adapted to the firing of the Alberta fuels, as the depth of the fire-pot was large in comparison with its diameter. To maintain the fire for at least six hours at even a low rate of combustion, it was difficult to fire the requisite quantity of fuel using one side of the grate only.

PRELIMINARY DECISIONS AND PROCEDURE

It was decided at the outset of the investigation to make tests on each fuel at three different rates of combustion, viz., a low, an intermediate, and a high load on the boiler. As the apparatus was installed in duplicate two tests could be made at one time and preferably on the same fuel when the two furnaces were operating together. It was, therefore, decided that four tests at least should be made on each fuel. The first two tests were

made simultaneously, one in each furnace, and were so regulated that approximately 99,000 B.T.U. per hour were delivered by the furnace to the cooling water. A comparison of the results of these two tests gave a good check on the accuracy with which the fires were judged. The remaining two tests were made simultaneously sometime later, and were so regulated that approximately 66,000 and 132,000 B.T.U. per hour respectively were delivered by the furnace to the cooling water.

Before starting a test the interval between firings was set, thus determining the length of fire-period, as was also the weight of raw fuel to be charged at the beginning of each of these fire-periods. The time interval between firings and the definite weight of fuel to be fired were fixed for each fuel according to the rate of combustion required, and the quality and bulkiness of the fuel to be tested. From previous knowledge as to the quality of similar fuels and from experience obtained in operating the furnaces for a preliminary fire-period or so, some knowledge was gained of the draught settings necessary to maintain a constant rate of combustion, so as to deliver the heat output desired.

The tests were continued until a sufficient quantity of fuel had been consumed to permit the error in judging the fire at the end of the test to be reduced so as not to be greater than 2 per cent. The error made in judging the fire, it was estimated would not exceed 20 pounds of fuel; therefore by continuing the test until 1,000 pounds of fuel were consumed this maximum was not exceeded.

The water meters were tested before and after each test to determine their accuracy, and to maintain the same conditions for each test the flues and furnaces were thoroughly cleaned before the start of every test.

PROCEDURE DURING TEST

Inasmuch as the continuous fire method of starting and stopping the tests was adopted, the fire was first lit in the furnace some 12 to 24 hours before the commencement of the test to ensure that a proper fuel bed, containing the correct proportion of ash and unburned fuel, would be built up before the start of the test. Then at the beginning a definite weight of fuel, fixed according to the rate of combustion required and the quality and bulkiness of the fuel to be tested, was charged onto the fuel bed, and afterwards at predetermined intervals throughout the test. At the end of each of these periods the fire was shaken, and when necessary, sliced, thus leaving the fuel bed in a condition similar to that at the beginning. This method of charging fuel was then repeated for the succeeding fire-periods. Careful note was made of each time the draughts or the damper settings were altered, but it was the endeavour not to touch or alter the draughts unless absolutely necessary, and not more frequently than would be done by the average householder in the operation of his own furnace. Before charging fuel at the end of each definite period, the grates were shaken and the refuse which had been shaken down from the previous fire-period was carefully removed and weighed and then stored away to be sampled at the end of the test. Careful record was kept of the weight of all refuse removed and the weight of fuel fired. When the requisite quantity of fuel had been burned, the test was ended at the nearest firing time in the manner described above.

The rate of flow of the cooling water was set for a constant value of two, three, or four gallons per minute for tests made at the low, intermediate, and high rates of combustion respectively, and the water meter was read every half hour. The inlet and outlet thermometers were read at the same time. As the water rate was considered to be constant for each half hour, the rise in temperature for that quantity of water which had passed the meter in 30 minutes was taken as the difference between the average outlet and inlet thermometer readings at the beginning and end of each half-hour period, and when multiplied by the weight of water passed through the radiation box during the 30-minute period gave the heat transferred, and was calculated for each half hour and totalled for the whole test. Thermometers were placed in the flow and return circulating-water headers at the back of the furnace. The temperature of the flue gas was measured by means of a pyrometer, the fire end being placed in the flue-pipe just at the offtake from the furnace. All these temperatures were read every half hour. CO_2, O_2, CO, and N_2 determinations were made on a sample of gas which was taken continuously over a period of one hour.

LENGTH OF FIRE-PERIOD AND QUANTITY OF FUEL FIRED PER PERIOD

The fire-periods varied in length from 8 to $2\frac{1}{2}$ hours; with the better grade fuels these periods were from 8 to 6 hours; but as the quality of the fuel decreased or the rate of burning increased, this time was shortened, in the extreme case, to $2\frac{1}{2}$ hours.

At the beginning of each fire-period fuel in sufficient quantity to last the requisite time, was fired. The quantity charged was determined largely according to the rate of combustion required and the calorific value and bulkiness of the fuel being tested; also, to some extent, from knowledge gained during preliminary runs on the same fuel.

DURATION OF TESTS AND QUANTITY OF FUEL FIRED DURING TEST

The duration of the tests varied from 40 to 120 hours, depending on the rate at which the heater was operated, and was so determined that approximately 1,000 pounds of fuel would be consumed. This quantity was, however, varied so that the time of ending would come at the end of a fire-period, and preferably during the hours from 8 to 12 a.m. Unfortunately, limitations of staff necessitated a reduction in the time of some of the tests. In these cases the duration of the test was reduced and was from 16 to 32 hours, when approximately 250 pounds of coal were burned. The tests were thus divided into two classes, one when approximately 1,000 pounds of fuel were burned and the other when approximately 250 pounds of fuel were burned. The former were termed "long tests" and the latter "short tests".

ATTENDANCE REQUIRED

As the furnaces were to be operated as closely as possible under conditions pertaining to household practice, the attendance to the fire after charging the fresh fuel, was reduced to a minimum. Neither the fuel bed nor the draughts were altered between firings, except when this was found

to be absolutely necessary, in order to maintain the correct combustion rate. Such attendance is permissible and might be said to be similar to the operation in a house, for when the house is too cold the draughts are opened and the check damper is closed; when too hot the draughts are closed and the check damper is opened. The attention the fire did receive, however, which might be considered as additional to what would be expected with an ordinary house heater, was given in accordance with the desire to have the tests fairly comparable upon a basis of equal loads or of equal heat transference, rather than to obtain the data of the attendance given the fire.

SAMPLING OF FUEL AND REFUSE

One sample of fuel was taken for each group of two tests when, as in most of the cases, the two heaters were operated simultaneously upon the same fuel. In order to avoid too many handlings, the quantity of fuel required for the tests was shovelled directly from the storage bin onto a clean sampling floor, and was cut out by means of the shoveling method, i.e. one shovelful in every four or five, according to the amount of fuel being sampled, was set aside in a separate pile. All of the lumps were then broken up into pieces no larger than 4 or 5 inches in diameter, and the sample was then coned and quartered down until approximately only 75 pounds were left. This quantity was sent directly to the chemical laboratory to be crushed, ground, and then riffled down for analysis. The remainder of the fuel left on the sampling floor was carried in sacks to the furnace room as required, each sack containing a predetermined weight of fuel sufficient for one fire-period. All the refuse, as it was removed from the furnace, either from the ash-pit or through the fire-door, was weighed, and stored in covered galvanized iron receptacles until the end of the test, when it was sent to the chemical laboratory for sampling and analysis.

ANALYSES OF FUEL AND REFUSE

All chemical analyses were made in the Chemical Laboratories of the Fuel Testing Division by chemists who were continually employed on this class of work. In general, screen and ultimate analyses were made on a sample collected by a member of the chemical staff, upon receipt of each different fuel as it was placed in storage, and a determination of the calorific value was made at that time. Further approximate analysis was made upon each new sample of fuel as obtained, prior to each test, and the ultimate analysis and calorific value were then calculated for it from the previous analysis which had been made. A sample of the refuse, which contained both ash and clinker, was analysed for the combustible content. After the test the chemist in charge submitted a report to the observers, which gave the proximate analysis, the calorific value, and ultimate analysis of the fuel as fired, as well as the combustible content of the refuse on a dry basis.

FLUE GAS ANALYSIS

The flue gases were sampled continuously and an analysis made every hour of the test. The sample was analysed in a conveniently arranged Orsat apparatus for CO_2, CO, and O_2; the N_2 being obtained by difference.

During the "short tests" it was found feasible to make analyses more often and accordingly they were made every half hour during these tests. The sample was drawn from the flue at the junction of the flue-pipe with the smoke collar of the furnace, at which point the fire end of the thermo-couple measuring flue-gas temperature was also located.

OBSERVATIONS MADE

At the start and every 30 minutes during the whole course of each test, the following observations were made and a record kept of same on suitable log forms.

(*a*) Water-meter reading. Scale calibrated in Imperial gallons and read to nearest gallon.

(*b*) Radiation tank inlet and outlet cooling-water temperatures. Thermometer scales calibrated in degrees Fahrenheit and read to nearest half degree.

(*c*) Circulating-water temperatures at the furnace—flow and return. Thermometer scales calibrated to two degrees Fahrenheit and read to nearest degree.

(*d*) Flue gas temperature. Pyrometer scale calibrated in ten degrees Fahrenheit and read to nearest five degrees.

(*e*) Room temperature. Thermometer scale calibrated to two degrees Fahrenheit and read to nearest degree.

(*f*) Draught pressure in flue. Draught gauge scale calibrated in 0·01 inch of water and read to nearest 0·0025 inch of water.

In addition to the above, an analysis was made of the flue gases each hour in the case of "long tests" and each half hour in the case of "short tests". The Orsat scale was calibrated in 0·2 per cent and was read to the nearest 0·1 per cent.

DIFFICULTIES

At the outset of the investigation great difficulty was experienced in obtaining a constant and steady flow of cooling water from the city supply main. A uniform flow of water through the meters was necessary because the flow was measured only every half hour, and in the calculations the flow was assumed to be constant over this period of time. To obviate the difficulty of obtaining a steady flow a storage tank was placed on a floor 7 feet above that on which the radiation tanks rested. The water in this storage tank was kept at a constant level by means of a ball and cock valve. The cooling water was delivered through parallel pipe-lines, by means of a rotary pump, motor driven, to both radiation tanks. By this means a very constant flow was obtained, the flow being affected only by the variation of the voltage on the electrical supply line.

The chief difficulty encountered in this method of testing fuels is that of judging the fire and so regulating it that the fuel bed will be in the same condition at the end of the test as it was at the start. As it is impossible to see more than the top and bottom of the fuel bed, which, under normal conditions, is 12 to 15 inches deep, judging the fire correctly is obviously a difficult matter. An error of 20 pounds, in judging the quantity of fuel on the grates, could be made, and if only 200 pounds of fuel were consumed and this error were made, it would mean an error of 10 per cent,

whereas if 1,000 pounds of fuel were consumed the error would only be 2 per cent. It was endeavoured during the tests to keep all errors within the limit of 2 per cent. When burning anthracites and cokes the difficulty in judging the fire was greater than when burning the bituminous and sub-bituminous fuels, as with the latter, the method of firing was from side to side of the fire-pot, and the quantity of fuel on the grates at any time was less and the fire could be judged more easily. The error made in judging the fire was apparent when the ratio of the ash fired to the ash removed was calculated. This ratio was almost invariably greater than unity, showing that a certain amount of ash was not recovered with the refuse. Some of this ash would be carried out of the furnace with the flue gases, but nearly all of it must have been held in the fuel bed, thus showing that the fuel bed was not in a stable condition at the start of the test, or else an error had been made in sampling the fuel or the refuse removed during the test. In order to minimize the first cause the fire was lit the night before the start of the test, as previously mentioned, and to reduce the error in sampling the greatest possible care was exercised in obtaining trustworthy samples of both fuel and refuse.

TEST DATA AND METHOD OF CALCULATING RESULTS

All the test data taken was recorded on suitable log forms drawn up especially for these tests and the results which were worked out from the observed data were then recorded on a suitable result sheet. A facsimile of the four log forms and the result sheet follows.

Data obtained from the Chemical Laboratories, such as proximate, ultimate, and screen analyses, calorific value and fuel ratio determinations, and combustible content value of the refuse, were submitted by the chemist in charge on his regular report sheet, from which it was copied onto the result sheet for each test.

FACSIMILE OF BLANK LOG FORMS

Heater Trial Form I—Cooling Water

HEATER TRIAL FORM I
SHEET NO.

FUELS AND FUEL TESTING DIVISION

Kind of Heater

Fuel

Date   No. of Trial

COOLING WATER

Thermometer at Outlet................................   Water meter correction at start........per cent.

Thermometer at Inlet..................................   Water meter correction at finish........per cent.

Time	Outlet temp. °F		Inlet temp. °F		Corrected temp. difference	Meter reading	Gallons in interval	Pounds corrected	B.T.U. in interval
	Reading	Corrected	Reading	Corrected					

Heater Trial Form II—Observations of Draught, Temperature, etc.

HEATER TRIAL FORM II
SHEET No.................................

FUELS AND FUEL TESTING DIVISION

Kind of Heater
Fuel
Date

No. of Trial...............................

OBSERVATIONS OF DRAUGHT TEMPERATURE, ETC.

Time	Draught, inches of water		Flue gas Temp. °F.	Room Temp. °F.	Temp. of circulating water		% CO_2 indicated
	In flue	Over fire			Flow °F.	Return °F.	

Heater Trial Form III—Fuel Charged and Refuse Removed

HEATER TRIAL FORM III
SHEET No...........................

FUELS AND FUEL TESTING DIVISION

Kind of Heater
Fuel
Date

No. of Trial.........................

FUEL CHARGED AND REFUSE REMOVED

Time	Pounds of fuel charged			Time	Pounds of refuse removed		
	Gross	Tare	Net		Gross	Tare	Net

Heater Trial Form IV—General Remarks

HEATER TRIAL FORM IV
SHEET No...........................

FUELS AND FUEL TESTING DIVISION

Kind of Heater
Fuel
Date

No. of Trial.........................

GENERAL REMARKS

Time	Observations

Heater Trial Form V—General Results

HEATER TRIAL FORM V

HOT-WATER DOMESTIC FURNACE TRIAL

GENERAL RESULTS

Trial No........................Duration........................hours..-load
Firings...at....................................hour intervals
Name of fuel...
Proximate analysis as fired—M................%; A................%; V.M...............%; F.C.............%
B. T. U. per lb....................
Ultimate analysis as fired—C....................%; H................%; A...............%; S..................%
N_2...........%; O_2...............%
Total quantity of fuel fired...lb.
Quantity of fuel fired per hour...lb.
Quantity of fuel fired per sq. ft. grate surface per hour..lb.
Analysis of refuse on dry basis—A..............................%; comb..%
Total quantity refuse removed..lb.
Total quantity ash and moisture-free fuel fired...lb.
Quantity ash and moisture-free fuel removed in refuse..lb.
Quantity ash and moisture-free fuel consumed..lb.
Total quantity ash fired based on proximate analysis...lb.
Total quantity ash removed based on analysis of refuse...lb.
Ratio $\frac{\text{ash fired}}{\text{ash removed}}$..
Average temperature circulating water——flow...°F
Average temperature circulating water——return...°F
Average draught in flue..inches of water
Average draught over fire..inches of water
Total quantity of heat transmitted to cooling water...B. T. U.
Quantity of heat transmitted to cooling water per hour...B. T. U.
Quantity of heat transmitted to cooling water per lb. fuel fired.......................................B. T. U.
Average temperature flue gases...°F
Average temperature room...°F
Analysis of dry flue gases, by volume, CO_2.................%; O_2...................%; CO...................%
N_2...................%.
Quantity of dry flue gases per lb. fuel as fired..lb.
Excess air..%
Load-rating developed..%
Quantity refuse removed per ton fuel fired...lb.
Quantity fuel fired per 100,000 B. T. U. transmitted to cooling water.................................lb.

HEAT ACCOUNT PER LB. OF FUEL AS FIRED	B. T. U.	Per cent
Total heat value of 1 lb. of fuel as fired, gross value................	....	100·0
Heat transmitted to the cooling water..............................	....	....
Loss due to total heat of steam formed from moisture in fuel, and that formed by combustion of hydrogen......................	....	....
Loss due to heat carried away in dry flue gases......................	....	....
Loss due to unburned ash and moisture-free fuel in refuse............	....	....
Loss due to unburned carbon monoxide.............................	....	....
Balance of heat account, errors of observation, radiation loss and unaccounted for..	....	....

General remarks:—...

....

....

The results were in general calculated by methods which are the same as those employed in calculating boiler trials made under the A. S. M. E. code. The carbon found in the refuse by analysis was assumed to have a heating value of 14,500 B.T.U. per pound. The following example shows in detail the calculations made for trial G-29-B.

Quantity of fuel fired..	761·25 lb.
Quantity of moisture fired (0·006 x 761·25) = ...	4·6 lb.
Quantity of dry fuel fired..	756·65 lb.
Quantity of ash fired (0·13 x 761·25) = ...	99·0 lb.
Quantity combustible fired..	657·6 lb.
Quantity of refuse removed..	113·0 lb.
Quantity of ash removed (0·816 x 113) = ...	92·2 lb.
Quantity of combustible in refuse....................................	20·8 lb.
Ratio $\dfrac{\text{ash fired}}{\text{ash removed}} = \dfrac{99\cdot0}{92\cdot2} =$	1·074
Estimated unconsumed combustible (1·074 x 20·8) = ...	22·3 lb.
Estimated combustible consumed (657·6 — 22·3) = ...	635·3 lb.
$\dfrac{\text{Carbon consumed}}{\text{Pound of fuel fired}} = 0\cdot832 \times \dfrac{635\cdot3}{657\cdot6} =$	0·804 lb.
$\dfrac{\text{Dry flue gas}}{\text{Pound of fuel fired}} = \dfrac{4 \times 13\cdot8 + 5\cdot6 + 700}{3\,(13\cdot8 + 0\cdot5)} \times 0\cdot804 =$	14·3 lb.
Excess air $= \dfrac{79 \times 5\cdot6}{21 \times 80\cdot1 - 79 \times 5\cdot6} \times 100 =$	35·7 %

"HEAT BALANCE"

Item		B.T.U.	Per cent
1. Total heat value of 1 lb. of fuel as fired, gross value........................		= 12,060	100·0
2. Heat transmitted to cooling water per lb. of fuel fired.............................	$\dfrac{6{,}799{,}880}{761\cdot25}$	= 8,930	74·0
3. Loss due to heat of steam formed from moisture in fuel, and that formed by combustion of hydrogen per lb. of fuel fired.....	295 − 212 = 83; 212 − 73 = 139·0; 83 x 0·48 = 39·8; 970·4; $\dfrac{0\cdot6 \times 9 \times 1{,}149\cdot2}{100}$	= 60	0·5
4. Loss due to heat carried away in dry flue gases per lb. of fuel fired..................	295 − 73 = 222; 222 x 0·24 x 14·3	= 760	6·3
5. Loss due to unburned ash and moisture-free fuel in refuse per lb. of fuel fired............	$\dfrac{22\cdot3 \times 14{,}500}{761\cdot25}$	= 420	3·5
6. Loss due to unburned carbon monoxide per lb. of fuel fired............................	$\dfrac{0\cdot5}{13\cdot8 + 0\cdot5} \times 0\cdot804 \times 10{,}150$	= 290	2·4
7. Balance of heat account, errors of observation, radiation loss, and that unaccounted for per lb. of fuel fired.........................	by difference	= 1,600	13·3

RESULTS OF TESTS

The detailed data and results of the 123 tests are given in Table VI which follows, but those tests that have been disregarded in the further discussion, and in the charts, graphs, and tables are marked with an asterisk. Charts I to VI are graphical representations of the calorific values of the fuels tested, and heat balances of the tests made. These charts are arranged in two groups of three each, one for each load on the furnace. In the first group are included the anthracites, cokes, and American smokeless, semi-bituminous coals, and in the second group, the Alberta coals.

TABLE VI

Detailed Data and Results of All Tests

Item No.	Item		American Anthracite			
1	Trial number		G-17-A*	G-20-A*	G-58-A	G-77-A*
2	Date of trial		7–3–23	10–29–23	5–4–25	10–14–25
3	Duration of test	Hours	84	72	120	32
4	Intervals between firings	"	12	8	8	8
	Proximate analysis of fuel, as fired—					
5	Moisture	Per cent	1·8	4·0	3·9	3·5
6	Ash	"	13·6	14·8	14·4	11·6
7	Volatile matter	"	5·5	5·5	6·2	6·1
8	Fixed carbon (by difference)	"	79·1	75·7	75·5	78·8
9	Gross calorific value of fuel, as fired	B.T.U. per lb.	12530	12030	12090	12760
	Ultimate analysis of fuel, as fired—					
10	Carbon	Per cent	....	....	76·1	78·5
11	Hydrogen	"	....	....	3·1	2·9
12	Ash	"	....	....	14·4	11·6
13	Sulphur	"	0·8	0·8	0·9	0·9
14	Nitrogen	"	....	....	0·8	0·9
15	Oxygen (by difference)	"	....	....	4·7	5·2
	Fuel and refuse—					
16	Fuel fired, total	Lb.	669·5	622·0	932·75	261·5
17	Fuel charged per fire period, average	"	95·6	69·1	62·2	65·4
18	Fuel fired per hour	"	8·0	8·6	7·8	8·2
19	Fuel fired per sq. ft. grate surface per hour	"	2·3	2·5	2·3	2·4
20	Fuel fired per therm delivered to cooling water	"	11·72	11·93	10·95	11·60
21	Refuse removed through fire-door	"	0·0	0·0	0·0	0·0
22	Refuse removed from ash-pit	"	118·5	126·75	159·5	52·0
23	Refuse removed, total	"	118·5	126·75	159·5	52·0
24	Refuse removed per ton of fuel fired	"	354·0	408·0	342·0	398·0
25	Total refuse as a percentage of the fuel fired	Per cent	17·7	20·4	17·1	19·9
26	Combustible matter in refuse	"	34·1	44·2	34·5	48·6
	Temperatures and draughts—					
27	Temperature of circulating water, flow	Deg. F.	151	133	127	132
28	Temperature of circulating water, return	"	122	101	99	103
29	Temperature of flue gases	"	315	280	300	250
30	Temperature of room	"	....	66	72	73
31	Draught in flue	Inch of water	0·017	0·017	0·010	0·025
	Analysis of flue gases by volume—					
32	Carbon dioxide	Per cent	....	....	12·4	12·7
33	Oxygen	"	....	....	7·6	7·2
34	Carbon monoxide	"	....	....	0·1	0·2
35	Nitrogen (by difference)	"	....	....	79·9	79·9
36	Weight dry flue gases per pound of fuel as fired	Lb.	....	....	13·9	13·4
37	Excess air	Per cent	....	....	55·7	51·3
	Rates and efficiencies—					
38	Heat delivered to cooling water per hour	B.T.U.	67950	72410	70940	70450
39	Heat delivered to cooling water per pound of fuel fired	"	8530	8380	9130	8620
40	Grate efficiency	Per cent	91·7	85·5	90·7	87·1
41	Overall thermal efficiency	"	68·1	69·7	75·5	67·6
	Heat account per pound of fuel, as fired—					
42	Gross calorific value per pound fuel, as fired	B.T.U.	12530	12030	12090	12760
43	Heat delivered to the cooling water	B.T.U.	8530	8380	9130	8620
		Per cent	68·1	69·7	75·5	67·6
44	Loss due to total heat of steam formed from moisture	B.T.U.	....	....	320	290
	in fuel and that formed by combustion of hydrogen	Per cent	....	....	2·6	2·3
45	Loss due to heat carried away in dry flue gases	B.T.U.	....	....	760	570
		Per cent	....	....	6·3	4·5
46	Loss due to unburned combustible matter in refuse	B.T.U.	1020	1700	1100	1590
		Per cent	8·1	14·1	9·1	12·5
47	Loss due to unburned carbon monoxide	B.T.U.	....	....	60	110
		Per cent	....	....	0·5	0·8
48	Balance of heat account; errors of observation, radiation, and that unaccounted for	B.T.U.	....	....	720	1580
		Per cent	....	....	6·0	12·3

Tests marked * have been discarded as not being representative of the fuel.

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

American Anthracite											Item No.
G-85-A*	**G-27-A***	**G-27-B***	**G-59-A**	**G-59-B**	**G-77-B***	**G-86-A***	**G-24-A***	**G-58-B**	**G-78-B***	**G-87-A***	
1–25–26	7–21–24	7–21–24	5–11–25	5–11–25	10–14–25	1–27–26	2–10–24	5–4–25	10–21–25	1–29–26	1
32	96	96	96½	96	24½	24	120	73	16½	16	2
8	8	8	8	8	8	8	8	8	8	8	3
8	8	8	8	8	8	8	8	8	8	8	4
3·4	3·3	3·3	3·7	3·7	3·5	3·4	3·3	3·9	3·5	3·4	5
14·4	14·1	14·1	14·6	14·6	11·6	14·4	15·7	14·4	11·6	14·4	6
6·5	6·2	6·2	6·2	6·2	6·1	6·5	6·3	6·2	6·1	6·5	7
75·7	76·4	76·4	75·5	75·5	78·8	75·7	74·7	75·5	78·8	75·7	8
12300	12250	12250	12090	12090	12760	12300	11990	12090	12760	12300	9
76·9	....	....	76·1	76·1	78·5	76·9	....	76·1	78·5	76·9	10
2·4	....	....	3·1	3·1	2·9	2·4	....	3·1	2·9	2·4	11
14·4	....	....	14·6	14·6	11·6	14·4	....	14·4	11·6	14·4	12
1·0	0·7	0·7	0·9	0·9	0·9	1·0	0·7	0·9	0·9	1·0	13
0·8	....	....	0·8	0·8	0·9	0·8	....	0·8	0·9	0·8	14
4·5	....	....	4·5	4·5	5·2	4·5	....	4·7	5·2	4·5	15
260·0	1186·0	1132·0	1115·0	1029·75	285·0	260·25	1922·0	1130·5	246·0	249·5	16
65·0	98·8	94·3	92·8	85·8	95·0	86·7	128·1	125·6	123·0	124·8	17
8·1	12·6	11·8	11·6	10·8	11·6	10·8	16·0	15·5	14·9	15·6	18
2·4	3·6	3·5	3·4	3·2	3·4	3·2	4·7	4·6	4·4	4·6	19
12·06	12·38	12·06	11·44	10·80	10·65	10·58	12·97	12·36	10·50	11·14	20
0·0	0·0	0·0	0·0	0·0	0·0	2·25	22·5	19·5	0·0	7·25	21
54·25	261·25	239·25	224·25	191·5	45·75	49·0	438·0	188·5	30·75	40·0	22
54·25	261·25	239·25	224·25	191·5	45·75	51·25	460·5	208·0	30·75	47·25	23
417·0	441·0	423·0	402·0	372·0	321·0	394·0	479·0	368·0	250·0	379·0	24
20·9	22·0	21·2	20·1	18·6	16·1	19·7	24·0	18·4	12·5	18·9	25
45·6	43·4	41·6	40·6	35·2	46·1	32·2	35·1	37·0	45·0	31·5	26
115	156	169	141	145	155	132	146	155	164	148	27
86	121	121	106	109	117	95	103	112	122	104	28
295	450	375	375	385	315	400	425	510	385	560	29
63	77	77	74	74	74	67	....	73	72	57	30
0·020	0·025	0·024	0·019	0·031	0·085	0·034	0·078	0·094	0·150	0·063	31
11·3	....	....	12·5	12·1	12·2	13·8	....	11·4	12·7	14·0	32
8·8	....	....	7·5	7·8	7·9	6·4	....	8·5	7·4	5·9	33
0·1	....	....	0·1	0·1	0·2	0·1	....	0·1	0·2	0·1	34
79·8	....	....	79·9	80·0	79·7	79·7	....	80·0	79·7	80·0	35
14·5	....	....	13·4	14·2	14·1	12·9	....	14·9	13·7	12·7	36
70·9	....	....	54·6	57·9	59·5	43·3	....	66·6	53·7	38·4	37
67350	99840	97810	100980	99320	109290	102480	123480	125330	141820	139960	38
8290	8080	8290	8740	9260	9400	9450	7710	8090	9510	8980	39
85·3	86·9	87·8	87·8	90·3	88·3	91·7	89·5	89·6	88·8	92·0	40
67·4	66·0	67·6	72·3	76·6	73·7	76·8	64·3	66·9	74·5	73·0	41
12300	12250	12250	12090	12090	12760	12300	11990	12090	12760	12300	42
8290	8080	8290	8740	9260	9400	9450	7710	8090	9510	8980	43
67·4	66·0	67·6	72·3	76·6	73·7	76·8	64·3	66·9	74·5	73·0	
250	....	....	330	330	300	260	....	350	310	280	44
2·0	....	....	2·7	2·7	2·3	2·1	....	2·9	2·4	2·3	
810	....	....	970	1060	820	1030	....	1560	1030	1530	45
6·6	....	....	8·0	8·8	6·4	8·4	....	12·9	8·1	12·4	
1750	1570	1460	1440	1150	1440	990	1230	1230	1380	960	46
14·2	12·8	11·9	12·0	9·5	11·3	8·1	10·3	10·2	10·8	7·8	
60	....	....	50	60	110	50	....	60	110	50	47
0·5	....	....	0·4	0·5	0·9	0·4	....	0·5	0·9	0·4	
1140	....	....	560	230	690	520	....	800	420	500	48
9·3	....	....	4·6	1·9	5·4	4·2	....	6·6	3·3	4·1	

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Item No.	Welsh Anthracite						Scotch Semi-anthracite			
1	**G-19-A***	**G-28-A**	**G-28-B**	**G-35-A**	**G-35-B**	**G-21-A**	**G-43-A**	**G-41-A**	**G-41-B**	**G-43-B**
2	10–14–23	7–28–24	7–28–24	10–6–24	10–6–24	11–19–23	12–8–24	11–24–24	11–24–24	12–8–24
3	72	120	120	96	96	120	120	96	96	80
4	8	8	8	8	8	8	8	8	8	8
5	2·2	2·3	2·3	1·8	1·8	2·7	3·0	2·9	2·9	3·0
6	5·2	4·8	4·8	5·3	5·3	4·2	6·8	7·1	7·1	6·8
7	7·7	7·6	7·6	7·8	7·8	8·3	10·0	10·0	10·0	10·0
8	84·9	85·3	85·3	85·1	85·1	84·8	80·2	80·0	80·0	80·2
9	14260	13930	13930	14130	14130	14260	13780	13760	13760	13780
10	....	....	....	85·9	85·9	....	82·5	82·3	82·3	82·5
11	....	....	....	3·3	3·3	....	3·6	3·6	3·6	3·6
12	....	....	....	5·3	5·3	....	6·8	7·1	7·1	6·8
13	0·9	0·9	0·9	1·2	1·2	0·9	0·7	0·7	0·7	0·7
14	....	....	....	1·0	1·0	....	1·8	1·8	1·8	1·8
15	....	....	....	3·3	3·3	....	4·6	4·5	4·5	4·6
16	480·75	809·25	811·75	923·75	901·75	1547·5	754·5	925·75	946·25	1081·25
17	53·4	53·9	54·1	77·0	75·1	103·2	50·3	77·1	78·9	108·1
18	6·7	6·7	6·8	9·6	9·4	12·9	6·3	9·6	9·9	13·5
19	2·0	2·0	2·0	2·8	2·8	3·8	1·8	2·8	2·9	4·0
20	10·40	9·60	9·78	9·48	9·35	9·57	9·44	9·57	9·68	10·24
21	0·0	0·0	0·0	0·0	0·0	10·0	0·0	0·0	0·0	21·0
22	46·5	46·0	35·75	41·5	37·25	78·75	49·0	62·75	70·25	47·75
23	46·5	46·0	35·75	41·5	37·25	88·75	49·0	62·75	70·25	68·75
24	193·0	114·0	88·0	90·0	83·0	115·0	130·0	136·0	148·0	127·0
25	9·7	5·7	4·4	4·5	4·1	5·7	6·5	6·8	7·4	6·4
26	72·3	45·4	40·6	49·7	52·9	45·8	29·1	25·2	30·6	21·9
27	131	146	150	155	156	152	123	146	143	156
28	101	118	117	122	118	107	97	112	106	113
29	225	305	260	400	395	395	290	400	380	520
30	72	75	75	73	73	....	71	75	75	73
31	0·016	0·019	0·027	0·040	0·056	0·084	0·017	0·057	0·047	0·096
32	10·7	....	....	10·7	10·6	....	11·8	12·3	12·3	12·4
33	....	....	....	8·8	9·0	....	7·7	7·4	7·2	6·8
34	....	....	....	0·3	0·3	....	0·3	0·2	0·2	0·2
35	....	....	....	80·2	80·1	....	80·2	80·1	80·3	80·6
36	....	....	....	18·5	18·5	....	16·6	16·2	16·0	16·2
37	....	....	....	70·3	73·2	....	56·5	53·3	50·9	46·5
38	64260	70300	69190	101550	100430	134720	66570	100600	101830	132080
39	9620	10420	10230	10550	10690	10450	10590	10450	10330	9770
40	85·4	95·7	96·5	94·4	93·6	96·2	96·9	97·3	96·5	97·9
41	67·5	74·8	73·4	74·7	75·7	73·3	76·8	75·9	75·1	71·0
42	14260	13930	13930	14130	14130	14260	13780	13760	13760	13780
43	9620	10420	10230	10550	10690	10450	10590	10450	10330	9770
	67·5	74·8	73·4	74·7	75·7	73·3	76·8	75·9	75·1	71·0
44	....	....	....	360	360	....	370	390	380	410
	....	....	....	2·6	2·5	....	2·7	2·8	2·8	3·0
45	....	....	....	1450	1430	....	870	1260	1170	1740
	....	....	....	10·3	10·1	....	6·3	9·2	8·5	12·6
46	1970	580	480	760	860	510	410	350	450	280
	13·8	4·2	3·4	5·4	6·1	3·6	3·0	2·5	3·3	2·0
47	....	....	....	220	220	....	200	130	130	130
	....	....	....	1·6	1·6	....	1·4	0·9	0·9	0·9
48	....	....	....	790	570	....	1340	1180	1300	1450
	....	....	....	5·4	4·0	....	9·8	8·7	9·4	10·5

Tests marked * have been discarded as not being representative of the fuel.

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Gas Coke								By-product Coke No. 1		Item No.
G-18-A*	**G-29-A**	**G-29-B**	**G-56-A**	**G-34-A**	**G-34-B**	**G-23-A**	**G-56-B**	**G-26-A***	**G-22-A***	1
10–2–23	8–11–24	8–11–24	4–20–25	9–29–24	9–29–24	12–15–23	4–20–25	3–16–24	12–1 23	2
72	96	96	120	96	96	120	66	120	120	3
8	8	8	8	6	6	6	6	8	6	4
9·4	0·6	0·6	0·2	1·0	1·0	0·8	0·2	0·1	0·6	5
11·7	13·0	13·0	12·1	11·3	11·3	13·1	12·1	13·4	12·6	6
1·6	1·9	1·9	1·9	1·9	1·9	1·9	1·9	1·8	1·6	7
77·3	84·5	84·5	85·8	85·8	85·8	84·2	85·8	84·7	85·2	8
10850	12060	12060	12230	12250	12250	11955	12230	11880	11980	9
....	83·2	83·2	84·4	84·5	84·5	....	84·4	....	....	10
....	0·6	0·6	0·6	0·6	0·6	....	0·6	....	....	11
....	13·0	13·0	12·1	11·3	11·3	....	12·1	....	....	12
0·8	1·0	1·0	1·0	1·1	1·1	1·0	1·0	1·9	1·9	13
....	1·1	1·1	1·1	1·1	1·1	....	1·1	....	....	14
....	1·1	1·1	0·8	1·4	1·4	....	0·8	....	....	15
541·0	748·0	761·25	902·0	1048·5	1037·25	1875·0	1007·5	978·75	1904·75	16
60·1	62·3	63·4	60·1	65·5	64·8	93·4	91·6	65·3	95·2	17
7·5	7·8	7·9	7·5	10·9	10·8	15·6	15·3	8·2	15·9	18
2·2	2·3	2·3	2·2	3·2	3·2	4·6	4·5	2·4	4·7	19
12·12	11·45	11·20	10·93	10·82	10·96	11·36	11·76	12·22	12·05	20
0·0	0·0	0·0	11·5	0·0	0·0	52·5	60·5	0·0	38·0	21
92·5	126·5	113·0	105·75	131·0	138 0	219·0	60·25	212·25	269·75	22
92·5	126·5	113·0	117·25	131·0	138·0	271·5	120·75	212·25	307·75	23
342·0	338·0	297·0	260·0	250·0	266·0	290·0	240·0	434·0	323·0	24
17·1	16·9	14·8	13·0	12·5	13·3	14·5	12·0	21·7	16·2	25
28·8	18·4	18·4	12·0	21·8	19·6	17·4	5·5	35·9	17·4	26
132	146	153	120	156	170	154	152	125	154	27
103	119	120	92	122	118	112	109	95	115	28
225	300	295	295	425	410	385	520	280	445	29
62	73	73	72	73	73	....	72	....	....	30
0·008	0·006	0·005	0·011	0·038	0·041	0·058	0·063	0·020	0·077	31
14·7	12·6	13·8	11·9	12·7	11·8	....	11·4	....	....	32
....	6·7	5·6	8·1	6·9	8·3	....	8·2	....	....	33
....	0·7	0·5	0·5	0·2	0·2	....	0·4	....	....	34
....	80·0	80·1	79·5	80·2	79·7	....	80·0	....	....	35
....	15·2	14·3	16·8	15·9	17·2	....	17·8	....	....	36
....	45·9	35·7	62·2	47·8	64·4	....	62·8	....	....	37
62020	68010	70830	68700	100870	98550	137480	129710	66680	131790	38
8250	8730	8930	9140	9240	9120	8800	8500	8180	8300	39
94·0	96·6	96·6	98·1	96·4	96·9	96·8	99·2	91·3	96·9	40
76·0	72·3	74·0	74·8	75·4	74·4	73·6	69·5	68·8	69·3	41
10850	12060	12060	12230	12250	12250	11955	12230	11880	11980	42
8250	8730	8930	9140	9240	9120	8800	8500	8180	8300	43
76·0	72·3	74·0	74·8	75·4	74·4	73·6	69·5	68·8	69·3	
....	60	60	60	70	70	....	70	....	....	44
....	0·5	0·5	0·5	0·6	0·6	....	0·6	....	....	
....	830	760	900	1350	1390	....	1910	....	....	45
....	6·9	6·3	7·4	11·0	11·3	....	15·6	....	....	
690	430	420	340	460	400	400	100	1090	380	46
6·4	3·6	3·5	2·0	3·8	3·3	3·3	0·8	9·2	3·2	
....	430	290	240	130	140	....	290	....	....	47
....	3·6	2·4	2·7	1·1	1·2	....	2·4	....	....	
....	1580	1600	1550	1000	1130	....	1360	....	....	48
....	13·1	13·3	12·6	8·1	9·2	....	11·1	....	....	

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Item No.	By-product Coke No. 2						By-product Coke No. 3				
1	**G-44-A**	**G-75-A***	**G-42-A**	**G-42-B**	**G-15-B***	**G-44-B**	**G-62-A***	**G-72-A**	**G-61-A**	**G-61-B**	**G-62-B**
2	12–15–24	9–30–25	12–1–24	12–1–24	9–30–25	12–15–24	6–8–25	9–9–25	5–25–25	5–25–25	6–8–25
3	120	32	96	96	24	72	120½	32½	96	96	78½
4	8	8	8	8	8	6	8	8	8	8	6
5	0·9	0·6	0·5	0·5	0·6	0·9	0·8	0·5	0·6	0·6	0·8
6	7·4	7·5	8·5	8·5	7·5	7·4	8·2	7·3	6·9	6·9	8·2
7	1·7	2·1	1·7	1·7	2·1	1·7	1·6	1·4	1·7	1·7	1·6
8	90·0	89·8	89·3	89·3	89·8	90·0	89·4	90·8	90·8	90·8	89·4
9	13040	13040	12940	12940	13040	13040	12900	12940	13100	13100	12900
10	87·6	87·7	86·9	86·9	87·7	87·6	87·8	88·9	89·2	89·2	87·8
11	0·8	0·8	0·8	0·8	0·8	0·8	0·6	0·6	0·6	0·6	0·6
12	7·4	7·5	8·5	8·5	7·5	7·4	8·2	7·3	6·9	6·9	8·2
13	0·7	0·7	0·7	0·7	0·7	0·7	1·7	1·7	1·7	1·7	1·7
14	0·8	0·8	0·8	0·8	0·8	0·8	0·9	0·9	0·9	0·9	0·9
15	2·7	2·5	2·3	2·3	2·5	2·7	0·8	0·6	0·7	0·7	0·8
16	836·0	225·5	996·5	997·0	248·0	1030·75	889·0	227·0	1079·75	1063·25	1154·75
17	55·7	56·4	83·0	83·1	82·7	85·9	59·3	56·7	90·0	88·6	88·8
18	7·0	7·0	10·4	10·4	10·3	14·3	7·4	7·0	11·3	11·1	14·7
19	2·1	2·1	3·0	3·1	3·0	4·2	2·2	2·1	3·3	3·3	4·3
20	10·18	10·37	10·34	10·25	9·90	10·57	....	10·50	10·91	11·16	10·83
21	0·0	0·0	5·5	7·0	0·0	9·5	20·25	0·0	34·5	31·25	48·25
22	58·25	20·5	70·0	70·0	15·25	54·75	51·75	15·0	55·75	78·75	40·0
23	58·25	20·5	75·5	77·0	15·25	64·25	72·0	15·0	90·25	110·0	88·25
24	139·0	182·0	152·0	154·0	123·0	125·0	162·0	132·0	167·0	207·0	153·0
25	7·0	9·1	7·6	7·7	6·1	6·2	8·1	6·6	8·4	10·3	7·6
26	14·4	34·8	10·8	9·8	15·9	8·9	16·3	25·2	27·4	34·8	12·0
27	125	135	144	141	157	157	140	142	145	149	178
28	97	108	110	104	120	114	113	116	110	113	132
29	295	235	410	385	310	470	325	250	410	415	525
30	70	71	72	72	71	70	78	76	74	74	80
31	0·008	0·009	0·031	0·041	0·055	0·060	0·025	0·017	0·040	0·042	0·069
32	13·6	15·3	11·9	12·1	13·2	13·5	13·1	12·6	12·8	12·4	13·6
33	6·3	4·4	8·3	8·1	7·2	6·4	6·9	7·2	7·3	7·7	6·5
34	0·5	1·2	0·4	0·3	0·5	0·3	0·5	0·2	0·5	0·4	0·4
35	79·6	79·1	79·4	79·5	79·1	79·8	79·5	80·0	79·4	79·5	79·5
36	15·5	12·9	17·4	17·5	16·0	16·0	16·1	17·1	16·5	16·9	15·7
37	42·4	26·5	64·8	62·2	52·1	43·2	48·5	51·2	52·8	57·3	44·4
38	68400	68000	100300	101340	104350	135400	....	66530	102990	99300	135690
39	9820	9640	9670	9760	10100	9460	....	9520	9160	8960	9230
40	98·6	95·7	98·9	99·0	98·5	99·2	98·2	97·3	97·2	96·0	98·8
41	75·3	73·9	74·7	75·5	77·5	72·5	....	73·6	69·9	68·4	71·6
42	13040	13040	12940	12940	13040	13040	12900	12940	13100	13100	12900
43	9820	9640	9670	9760	10100	9460	....	9520	9160	8960	9230
	75·3	73·9	74·7	75·5	77·5	72·5	....	73·6	69·9	68·4	71·6
44	80	80	90	90	80	90	60	60	60	70	70
	0·6	0·6	0·7	0·7	0·6	0·7	0·5	0·5	0·5	0·5	0·6
45	840	510	1410	1310	920	1530	950	710	1330	1380	1680
	6·4	3·9	10·9	10·1	7·1	11·7	7·4	5·5	10·2	10·5	13·0
46	180	580	150	130	200	110	230	350	380	530	160
	1·4	4·5	1·2	1·0	1·5	0·8	1·8	2·7	2·9	4·1	1·3
47	310	620	280	210	320	190	320	140	330	270	250
	2·4	4·8	2·2	1·6	2·4	1·5	2·5	1·1	2·5	2·1	1·9
48	1810	1610	1340	1440	1420	1660	....	2160	1840	1890	1500
	13·9	12·3	10·3	11·1	10·9	12·8	....	16·6	14·0	14·4	11·6

Tests marked * have been discarded as not being representative of the fuel.

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

By-product Coke No. 4			American Smokeless Semi-bituminous No. 1.							Item No.
G-80-A	**G-80-B**	**G-81-B**	**G-45-A**	**G-76-A***	**G-82-A***	**G-40-A**	**G-40-B**	**G-76-B***	**G-82-B***	1
11–4–25	11–4–25	12–9–25	1–5–25	10–7–25	12–16–25	11–17–24	11–17–24	10–7–25	12–16–25	2
32	24	18½	120	32	32	96	96	24	24	3
8	8	6	8	8	8	8	8	8	8	4
0·8	0·8	0·5	0·8	1·3	1·0	0·8	0·8	1·3	1·0	5
7·1	7·1	6·8	8·1	8·3	8·7	9·0	9·0	8·3	8·7	6
1·8	1·8	1·1	19·8	20·0	20·1	19·7	19·7	20·0	20·1	7
90·3	90·3	91·6	71·3	70·4	70·2	70·5	70·5	70·4	70·2	8
12960	12960	13120	14060	14120	14180	13930	13930	14120	14180	9
88·6	88·6	89·1	81·0	80·0	80·3	80·1	80·1	80·0	80·3	10
0·7	0·7	0·7	4·5	4·5	4·5	4·5	4·5	4·5	4·5	11
7·1	7·1	6·8	8·1	8·3	8·7	9·0	9·0	8·3	8·7	12
1·5	1·5	1·6	2·8	3·2	2·7	2·7	2·7	3·2	2·7	13
....	....	....	1·4	1·3	1·3	1·3	1·3	1·3	1·3	14
....	....	....	2·2	2·7	2·5	2·4	2·4	2·7	2·5	15
240·0	257·75	287·5	878·75	280·5	244·75	981·0	960·5	287·0	290·25	16
60·0	86·0	95·8	58·6	701·1	61·2	81·7	80·0	95·7	96·8	17
7·5	10·7	15·5	7·3	8·8	7·6	10·2	10·0	11·9	12·1	18
2·2	3·2	4·6	2·1	2·6	2·3	3·0	2·9	3·5	3·5	19
10·83	10·23	11·38	10·79	12·75	11·27	10·91	10·72	12·0	....	20
0·0	0·0	3·75	6·75	0·0	0·0	6·75	11·5	0·0	2·5	21
21·5	15·25	20·75	66·25	45·75	24·25	65·25	60·75	28·25	17·25	22
21·5	15·25	24·5	73·0	45·75	24·25	72·0	72·25	28·25	19·75	23
179·0	118·0	170·0	166·0	326·0	198·0	147·0	150·0	197·0	136·0	24
9·0	5·9	8·5	8·3	16·3	9·9	7·3	7·5	9·8	6·8	25
39·1	27·3	29·3	26·5	58·8	39·4	20·3	13·6	43·4	20·6	26
124	146	152	127	133	114	140	136	152	137	27
94	109	108	99	105	87	107	101	116	97	28
290	290	410	400	325	330	465	440	420	435	29
73	73	76	76	71	75	74	74	71	76	30
0·001	0·058	0·140	0·041	0·034	0·034	0·088	0·063	0·128	0·154	31
14·3	11·8	13·4	9·3	11·5	9·5	9·2	9·7	10·6	10·2	32
5·5	8·3	7·2	10·1	7·9	10·2	10·4	9·5	8·7	9·5	33
0·5	0·5	0·2	0·2	0·0	0·1	0·2	0·3	0·1	0·1	34
79·7	79·4	79·2	80·4	80·6	80·2	80·2	80·5	80·6	80·2	35
14·5	17·6	16·1	20·6	15·2	19·6	20·7	19·7	17·4	19·0	36
35·1	64·8	52·0	89·6	58·4	91·7	95·2	79·8	68·3	80·4	37
69200	104960	136500	67860	68800	67820	93640	93330	99600	....	38
9230	9770	8790	9270	7850	8870	9160	9330	8330	....	39
95·1	97·1	97·0	96·8	86·9	93·8	97·5	98·4	93·0	97·5	40
71·2	75·4	67·0	65·9	55·6	62·6	65·8	67·0	59·0	....	41
12960	12960	13120	14060	14120	14180	13930	13930	14120	14180	42
9230	9770	8790	9270	7850	8870	9160	9330	8330	....	43
71·2	75·2	67·0	65·9	55·6	62·6	65·8	67·0	59·0	....	
70	70	80	480	470	470	500	490	490	490	44
0·5	0·5	0·6	3·4	3·3	3·3	3·6	3·5	3·5	3·5	
760	920	1290	1590	930	1200	1940	1730	1460	1640	45
5·9	7·1	9·8	11·3	6·6	8·5	13·9	12·4	10·3	11·6	
660	380	410	430	1720	820	330	210	920	330	46
5·1	2·9	3·1	3·1	12·2	5·8	2·4	1·5	6·5	2·3	
290	360	130	170	....	80	170	240	70	80	47
2·2	2·8	1·0	1·2	0·0	0·6	1·2	1·7	0·5	0·6	
1950	1460	2420	2120	3150	2740	1830	1930	2850	....	48
15·1	11·3	18·5	15·1	22·3	19·2	13·1	13·9	20·2	....	

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Item No.	American Smokeless Semi-bituminous No. 1		American Smokeless Semi-bituminous No. 2				Alberta Semi-bituminous			
1	**G-83-B***	**G-45-B**	**G-57-A**	**G-60-A**	**G-60-B**	**G-57-B**	**G-55-A**	**G-71-A***	**G-79-A***	**G-48-A**
2	12-29-25	1-5-25	4-27-25	5-18-25	5-18-25	4-27-25	3-30-25	9-2-25	10-28-25	2-2-25
3	$24\frac{1}{2}$	78	120	$96\frac{1}{2}$	$97\frac{1}{2}$	79	120	32	32	96
4	8	6	8	8	8	6	8	8	8	8
5	1·0	0·8	0·6	1·0	1·0	0·6	0·9	0·7	0·9	1·0
6	8·8	8·1	10·0	11·4	11·4	10·0	13·4	13·2	12·7	13·0
7	19·2	19·8	16·0	15·6	15·6	16·0	15·7	16·1	16·4	15·8
8	71·0	71·3	73·4	72·0	72·0	73·4	70·0	70·0	70·0	70·2
9	14130	14060	14020	13750	13750	14020	13300	13260	13310	13340
10	80·2	81·0	80·3	78·8	78·8	80·3	77·7	78·0	78·3	77·9
11	4·5	4·5	4·3	4·3	4·3	4·3	4·1	4·1	4·1	4·1
12	8·8	8·1	10·0	11·4	11·4	10·0	13·4	13·2	12·7	13·0
13	2·7	2·8	1·8	1·7	1·7	1·8	0·7	0·7	0·7	0·7
14	1·3	1·4	1·2	1·2	1·2	1·2	1·3	1·4	1·4	1·4
15	2·5	2·2	2·4	2·6	2·6	2·4	2·8	2·6	2·8	2·9
16	273·0	1041·0	863·25	1042·0	1037·5	1086·75	922·5	255·0	252·25	1088·0
17	91·0	80·1	57·5	86·8	86·5	83·6	61·5	63·7	63·1	90·7
18	11·1	13·3	7·2	10·9	10·6	13·8	7·7	8·0	7·9	11·3
19	3·3	3·9	2·1	3·2	3·1	4·1	2·3	2·3	2·3	3·3
20	11·70	11·30	10·55	11·20	11·03	11·25	11·18	12·00	12·28	11·34
21	2·0	22·5	4·25	0·0	7·75	35·75	16·75	9·5	0·0	55·0
22	23·5	58·75	105·25	128·75	111·25	70·75	150·75	27·75	28·0	82·25
23	25·5	81·25	109·5	128·75	119·0	106·5	167·5	37·25	28·0	137·25
24	187·0	156·0	254·0	247·0	229·0	196·0	363·0	292·0	222·0	252·0
25	9·3	7·8	12·7	12·3	11·5	9·8	18·2	14·7	11·1	12·6
26	20·9	16·4	24·9	25·5	17·3	9·4	49·3	45·8	54·8	30·9
27	130	146	124	140	146	151	117	143	121	146
28	93	107	96	107	111	110	88	117	94	111
29	410	605	380	490	500	600	350	295	285	525
30	69	76	73	73	73	73	72	73	71	75
31	0·132	0·117	0·063	0·107	0·113	0·139	0·031	0·060	0·067	0·049
32	9·6	9·0	8·8	8·9	10·2	11·3	9·7	9·6	8·7	10·6
33	10·2	10·2	10·8	11·1	9·4	8·0	9·8	10·5	11·3	9·0
34	0·1	0·2	0·1	0·1	0·1	0·1	0·1	0·0	0·2	0·0
35	80·1	80·6	80·3	79·9	80·3	80·6	80·4	79·9	79·8	80·4
36	20·1	21·5	21·6	20·8	18·6	17·5	16·8	17·6	18·0	17·1
37	92·0	90·9	102·3	109·4	78·7	59·6	84·7	97·7	114·0	72·7
38	95280	118160	68100	96400	96520	122320	68710	66300	64220	99960
39	8550	8850	9470	8930	9070	8890	8940	8320	8150	8820
40	97·4	98·3	96·3	95·6	97·3	98·8	84·8	87·0	82·2	93·2
41	60·5	63·0	67·5	64·9	65·9	63·4	67·2	62·7	61·2	66·1
42	14130	14060	14020	13750	13750	14020	13300	13260	13310	13340
43	8550	8850	9470	8930	9070	8890	8940	8320	8150	8820
	60·5	63·0	67·5	64·9	65·9	63·4	67·2	62·7	61·2	66·1
44	490	520	460	480	480	500	430	420	420	460
	3·5	3·7	3·3	3·5	3·5	3·6	3·2	3·2	3·2	3·4
45	1640	2730	1590	2060	1910	2210	1120	940	920	1850
	11·6	19·4	11·3	15·0	13·9	15·8	8·4	7·1	6·9	13·9
46	330	230	480	570	350	150	1890	1630	2220	850
	2·3	1·6	3·4	4·1	2·5	1·0	14·2	12·3	16·7	6·4
47	80	180	90	80	80	70	70	....	150	....
	0·6	1·3	0·6	0·6	0·6	0·5	0·6	....	1·1	....
48	3040	1550	1930	1630	1860	2200	850	1950	1450	1360
	21·5	11·0	13·9	11·9	13·6	15·7	6·4	14·7	10·9	10·2

Tests marked * have been discarded as not being representative of the fuel.

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Alberta Semi-bituminous					Alberta Sub-bituminous No. 1						Item No.
G-48-B	**G-72-B***	**G-79-B***	**G-55-B**	**G-71-B***	**G-54-A**	**G-46-A**	**G-46-B**	**G-67-B***	**G-54-B**	**G-68-B***	1
2-2-25	9-9-25	10-28-25	3-30-25	9-2-25	3-23-25	1-19-25	1-19-25	8-5-25	3-23-25	8-12-25	2
96	24½	24	72	18½	104	78	78	24	52	16	3
8	8	8	6	6	8	6	6	6	4	4	4
1·0	1·0	0·9	0·9	0·7	9·0	9·7	9·7	8·2	9·0	8·0	5
13·0	9·1	12·7	13·4	13·2	7·7	8·0	8·0	6·9	7·7	7·0	6
15·8	15·9	16·4	15·7	16·1	32·6	32·2	32·2	34·6	32·6	33·7	7
70·2	74·0	70·0	70·0	70·0	50·7	50·1	50·1	50·3	50·7	51·3	8
13340	13940	13310	13300	13260	11240	11110	11110	11610	11240	11690	9
77·9	81·4	78·3	77·7	78·0	66·2	65·4	65·4	67·4	66·2	67·5	10
4·1	4·3	4·1	4·1	4·1	5·0	5·1	5·1	5·1	5·0	5·1	11
13·0	9·1	12·7	13·4	13·2	7·7	8·0	8·0	6·9	7·7	7·0	12
0·7	0·8	0·7	0·7	0·7	0·3	0·3	0·3	0·3	0·3	0·3	13
1·4	1·4	1·4	1·3	1·4	1·0	1·0	1·0	1·0	1·0	1·0	14
2·9	3·0	2·8	2·8	2·6	19·8	20·2	20·2	19·3	19·8	19·1	15
1071·75	270·75	271·25	1087·75	287·75	1003·0	1174·25	1181·75	334·5	1022·25	309·0	16
89·3	90·3	90·4	90·6	95·9	77·2	90·3	90·9	83·6	78·6	77·2	17
11·2	11·1	11·3	15·1	15·6	9·6	15·1	15·2	13·9	19·7	19·3	18
3·3	3·3	3·3	4·4	4·6	2·8	4·4	4·5	4·1	5·8	5·7	19
11·19	11·52	10·75	11·39	12·59	13·89	15·27	14·90	13·85	14·99	14·33	20
77·5	10·5	2·5	78·0	26·25	16·25	48·75	47·5	6·0	32·75	9·0	21
59·75	21·75	24·0	86·75	22·75	96·75	65·25	61·0	19·0	56·0	23·75	22
137·25	32·25	26·5	164·75	49·0	113·0	114·0	108·5	25·0	88·75	32·75	23
256·0	238·0	195·0	303·0	341·0	225·0	194·0	184·0	149·0	174·0	212·0	24
12·8	11·9	9·8	15·1	17·0	11·3	9·7	9·2	7·5	8·7	10·6	25
20·5	35·2	45·8	20·5	28·3	37·6	22·8	17·9	36·9	26·2	37·6	26
139	157	148	151	170	117	144	141	162	149	175	27
103	123	111	107	131	88	110	104	126	105	133	28
515	455	340	620	520	410	570	575	405	670	575	29
75	74	71	73	74	73	73	73	77	73	75	30
0·066	0·065	0·113	0·107	0·108	0·015	0·058	0·045	0·092	0·078	0·067	31
10·6	13·2	11·2	11·2	12·9	11·3	11·6	10·5	12·2	10·2	12·7	32
8·9	6·8	8·7	8·2	7·1	8·2	7·1	8·3	7·2	9·2	7·0	33
0·1	0·1	0·1	0·0	0·1	0·1	0·5	0·4	0·5	0·1	0·2	34
80·4	79·9	80·0	80·6	80·0	80·4	80·8	80·8	80·1	80·5	80·1	35
17·5	14·6	15·2	16·7	14·4	13·8	12·9	14·7	12·7	15·5	12·6	36
71·4	47·1	69·2	62·0	50·1	62·2	49·4	63·0	51·1	75·4	49·0	37
99850	95900	105000	132630	123570	69450	98560	101690	100600	131100	134800	38
8940	8680	9300	8780	7950	7200	6550	6710	7220	6670	6980	39
96·1	94·5	87·6	96·0	93·9	94·4	97·1	97·9	95·3	96·7	95·1	40
67·0	62·3	69·9	66·0	60·0	64·1	58·9	60·4	62·2	59·3	59·7	41
13340	13940	13310	13300	13260	11240	11110	11110	11610	11240	11690	42
8940	8680	9300	8780	7950	7200	6550	6710	7220	6670	6980	43
67·0	62·3	69·9	66·0	60·0	64·1	58·9	60·4	62·2	59·3	59·7	
460	470	430	480	460	540	590	590	550	600	590	44
3·4	3·4	3·2	3·6	3·5	4·8	5·3	5·3	4·7	5·3	5·0	
1850	1340	980	2190	1540	1120	1570	1770	1000	2220	1510	45
13·9	9·6	7·3	16·5	11·6	10·0	14·1	15·9	8·6	19·8	12·9	
490	720	1550	500	760	670	340	250	580	400	610	46
3·7	5·2	11·6	3·8	5·7	5·9	3·1	2·2	5·0	3·6	5·2	
70	60	60	....	....	60	270	240	260	60	100	47
0·5	0·4	0·5	....	....	0·5	2·4	2·2	2·3	0·5	0·9	
1530	2670	990	1350	2550	1650	1790	1550	2000	1290	1900	48
11·5	19·1	7·5	10·1	19·2	14·7	16·2	14·0	17·2	11·5	16·3	

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Item No.	Alberta Sub-bituminous No. 2								
1	**G-53-A**	**G-73-A***	**G-81-A***	**G-49-A**	**G-49-B**	**G-65-B***	**G-66-B***	**G-73-B***	**G-53-B**
2	3-16-25	9-16-25	12-9-25	2-9-25	2-9-25	7-2-25	7-31-25	9-16-25	3-16-25
3	104	32	32	66	$72\frac{1}{2}$	24	24	24	52
4	8	8	8	6	6	6	6	6	4
5	8·8	7·3	7·9	8·9	8·9	8·0	7·9	7·3	8·8
6	10·3	9·7	10·0	9·3	9·3	9·8	9·9	9·7	10·3
7	34·1	35·7	34·3	34·5	34·5	34·7	34·8	35·7	34·1
8	46·8	47·3	47·8	47·3	47·3	47·5	47·4	47·3	46·8
9	10740	11100	11110	10860	10860	10910	11000	11100	10740
10	63·0	64·6	63·9	63·7	63·7	64·0	64·1	64·6	63·0
11	5·1	5·0	5·0	5·1	5·1	5·0	5·0	5·0	5·1
12	10·3	9·7	10·0	9·3	9·3	9·8	9·9	9·7	10·3
13	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·2
14	0·8	0·8	0·8	0·8	0·8	0·8	0·8	0·8	0·8
15	20·6	19·7	20·1	20·9	20·9	20·2	20·0	19·7	20·6
16	1068·5	329·25	329·25	1011·0	1123·5	351·5	353·25	351·75	1094·5
17	82·2	82·3	82·3	91·9	93·6	87·9	88·3	87·9	84·2
18	10·3	10·3	10·3	15·3	15·5	14·6	14·7	14·6	21·1
19	3·0	3·0	3·0	4·5	4·6	4·3	4·3	4·3	6·2
20	15·04	15·15	14·35	15·18	15·82	14·95	14·84	15·0	16·16
21	28·0	4·0	4·5	45·75	63·75	5·25	9·75	14·75	60·5
22	124·75	29·5	38·5	67·0	83·5	32·75	34·25	21·75	83·0
23	152·75	33·5	43·0	112·75	147·25	38·0	44·0	36·5	143·5
24	286·0	203·0	261·0	223·0	262·0	216·0	249·0	208·0	262·0
25	14·3	10·2	13·1	11·1	13·1	10·8	12·5	10·4	13·1
26	35·5	38·3	34·1	20·6	18·2	40·3	40·3	24·1	29·7
27	116	139	119	146	139	155	159	157	149
28	86	113	89	111	102	119	123	122	104
29	410	350	340	595	515	425	420	475	630
30	73	71	74	76	76	73	71	70	74
31	0·014	0·013	0·011	0·058	0·090	0·084	0·073	0·026	0·086
32	10·7	12·3	13·3	12·6	11·1	11·8	12·6	10·9	11·1
33	8·8	7·6	6·3	6·6	8·6	6·4	....	8·6	8·1
34	0·1	0·4	0·2	0·1	0·1	0·6	....	0·2	0·2
35	80·4	79·7	80·2	80·7	80·2	81·2	....	80·3	80·6
36	13·6	11·9	11·2	12·3	13·9	11·9	....	14·1	13·2
37	70·0	55·9	41·9	44·4	67·6	42·1	....	67·5	60·8
38	68310	67870	71700	100870	97900	97990	99140	97670	130210
39	6650	6600	6970	6580	6320	6690	6740	6660	6190
40	93·0	92·8	93·7	97·0	97·5	91·9	91·9	96·3	94·6
41	61·9	59·5	62·7	60·6	58·2	61·3	61·3	60·0	57·6
42	10740	11100	11110	10860	10860	10910	11000	11100	10740
43	6650	6600	6970	6580	6320	6690	6740	6660	6190
	61·9	59·5	62·7	60·6	58·2	61·3	61·3	60·0	57·6
44	550	530	530	590	570	550	550	560	600
	5·1	4·8	4·8	5·4	5·2	5·0	5·0	5·0	5·6
45	1100	800	720	1530	1460	1010	....	1370	1760
	10·2	7·2	6·5	14·1	13·4	9·3	....	12·3	16·4
46	820	870	750	350	300	960	960	450	630
	7·6	7·8	6·7	3·2	2·8	8·8	8·7	4·1	5·9
47	60	190	90	50	60	290	....	110	110
	0·6	1·7	0·8	0·5	0·6	2·7	....	1·0	1·0
48	1560	2110	2050	1760	2150	1410	....	1950	1450
	14·6	19·0	18·5	16·2	19·8	12·9	....	17·6	13·5

Tests marked * have been discarded as not being representative of the fuel.

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Alberta Sub-bituminous No. 3						Alberta Domestic No. 1				Item No.
G-52-A	**G-84-A***	**G-47-A**	**G-47-B**	**G-84-B***	**G-52-B**	**G-51-A**	**G-50-A**	**G-50-B**	**G-51-B**	1
3–9–25	1–14–26	1-26–25	1-26–25	1–13–26	3–9–25	3–2–25	2–16–25	2–16-25	3–2–25	2
104	32	78	78½	24	48	96	60	60	48	3
8	8	6	6	6	4	8	6	6	4	4
10·0	9·7	10·3	10·3	9·7	10·0	18·8	18·7	18·7	18·8	5
10·7	9·4	10·3	10·3	9·4	10·7	7·9	7·5	7·5	7·9	6
32·7	35·7	32·7	32·7	35·7	32·7	30·1	30·2	30·2	30·1	7
46·6	45·2	46·7	46·7	45·2	46·6	43·2	43·6	43·6	43·2	8
10820	11140	10840	10840	11140	10820	9390	9420	9420	9390	9
61·6	62·8	61·7	61·7	62·8	61·6	56·6	57·0	57·0	56·6	10
5·5	5·5	5·5	5·5	5·5	5·5	5·8	5·8	5·8	5·8	11
10·7	9·4	10·3	10·3	9·4	10·7	7·9	7·5	7·5	7·9	12
0·6	0·7	0·6	0·6	0·7	0·6	0·4	0·4	0·4	0·4	13
1·6	1·6	1·6	1·6	1·6	1·6	1·2	1·2	1·2	1·2	14
20·0	20·0	20·3	20·3	20·0	20·0	28·1	28·1	28·1	28·1	15
1021·75	330·75	1239·75	1268·0	351·0	1051·0	1070·0	1038·25	1038·0	1149·5	16
78·6	82·7	95·4	97·5	87·8	87·6	89·2	103·8	103·8	95·8	17
9·8	10·3	15·9	16·1	14·6	21·9	11·2	17·3	17·3	23·9	18
2·9	3·0	4·7	4·7	4·3	6·4	3·3	5·1	5·1	7·0	19
14·46	14·71	16·08	16·26	15·53	16·98	16·03	17·30	16·98	18·25	20
47·75	8·5	88·75	87·0	19·75	72·5	27·0	64·75	31·25	60·0	21
66·25	28·0	52·75	57·5	24·75	42·0	70·0	30·25	51·0	45·75	22
114·0	36·5	141·5	144·5	44·5	114·5	97·0	95·0	82·25	105·75	23
223·0	221·0	229·0	228·0	254·0	218·0	181·0	183·0	158·0	184·0	24
11·2	11·0	11·4	11·4	12·7	10·9	9·1	9·2	7·9	9·2	25
19·2	14·4	17·1	15·7	16·5	16·7	28·0	31·3	26·4	20·5	26
115	118	145	139	130	148	116	129	135	156	27
86	88	111	102	92	104	87	93	98	105	28
380	390	540	580	455	670	370	500	510	615	29
72	68	73	73	68	73	73	75	75	72	30
0·027	0·018	0·048	0·034	0·117	0·077	0·006	0·034	0·076	0·075	31
12·1	14·1	11·6	10·0	12·0	10·3	11·1	13·1	12·1	11·5	32
6·8	4·9	7·2	9·0	7·5	8·2	8·1	5·9	7·2	7·5	33
0·2	0·5	0·5	0·4	0·3	0·3	0·1	0·3	0·2	0·2	34
80·9	80·5	80·7	80·6	80·2	81·2	80·7	80·7	80·5	80·8	35
12·2	10·7	12·5	14·5	12·6	14·1	12·1	10·3	11·2	11·8	36
46·2	29·7	50·5	72·4	54·3	61·3	60·7	37·9	50·7	53·7	37
67920	70240	98820	99300	94110	129030	69510	100060	101840	131150	38
6910	6800	6220	6150	6440	5890	6240	5780	5890	5480	39
96·8	98·1	97·3	97·6	97·7	97·3	95·8	95·4	96·4	97·2	40
63·9	61·0	57·4	56·7	57·8	54·4	66·3	61·4	62·5	58·4	41
10820	11140	10840	10840	11140	10820	9390	9420	9420	9390	42
6910	6800	6220	6150	6440	5890	6240	5780	5890	5480	43
63·9	61·0	57·4	56·7	57·8	54·4	66·3	61·4	62·5	58·4	
590	590	630	640	610	660	620	650	650	680	44
5·5	5·3	5·8	5·9	5·5	6·1	6·6	6·9	6·9	7·2	
900	830	1400	1760	1170	2020	860	1050	1170	1540	45
8·3	7·5	12·9	16·2	10·5	18·7	9·2	11·1	12·4	16·4	
370	230	310	280	270	310	450	490	390	300	46
3·4	2·1	2·9	2·6	2·4	2·9	4·8	5·2	4·1	3·2	
100	210	250	240	150	170	50	120	90	100	47
0·9	1·9	2·3	2·2	1·4	1·6	0·5	1·3	1·0	1·1	
1950	2480	2030	1770	2500	1770	1170	1330	1230	1290	48
18·0	22·2	18·7	16·4	22·4	16·3	12·6	14·1	13·1	13·7	

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Item No.	Alberta Domestic No. 2						Alberta Domestic No. 3		
1	**G-39-A**	**G-70-A***	**G-33-A**	**G-33-B**	**G-39-B**	**G-70-B***	**G-38-A**	**G-69-A***	**G-32-A**
2	11-3-24	8-26-25	9-15-24	9-15-24	11-3-24	8-26-25	10-27-24	8-19-25	9-8-24
3	96	30½	66	66	48	15	84	30	65½
4	6	6	5	5	3	3	6	6	5
5	13·2	13·0	12·5	12·5	13·2	13·0	16·7	16·4	16·1
6	12·3	12·7	12·7	12·7	12·3	12·7	7·2	8·0	8·8
7	31·8	33·2	31·9	31·9	31·8	33·2	31·4	31·6	30·9
8	42·7	41·1	42·9	42·9	42·7	41·1	44·7	44·0	44·2
9	9600	9720	9620	9620	9600	9720	9600	9740	9470
10	55·6	55·4	55·7	55·7	55·6	55·4	55·3	55·0	54·6
11	5·4	5·3	5·3	5·3	5·4	5·3	5·7	5·6	5·5
12	12·3	12·7	12·7	12·7	12·3	12·7	7·2	8·0	8·8
13	1·1	1·2	1·2	1·2	1·1	1·2	0·5	0·5	0·5
14	1·3	1·3	1·3	1·3	1·3	1·3	1·2	1·2	1·2
15	24·3	24·1	23·8	23·8	24·3	24·1	30·1	29·7	29·4
16	1047·25	347·75	1135·25	1113·5	1196·0	360·0	972·0	399·75	1127·25
17	65·4	69·6	87·3	85·7	74·8	72·0	69·4	79·9	86·7
18	10·9	11·4	17·2	16·9	24·9	24·0	11·6	13·3	17·2
19	3·2	3·3	5·1	5·00	7·3	7·1	3·4	3·9	5·1
20	16·34	16·35	17·51	17·18	18·76	18·78	16·56	16·41	16·81
21	34·0	7·5	70·0	83·75	104·25	23·75	34·0	11·75	37·5
22	127·75	39·5	107·0	65·25	75·25	21·75	64·75	21·75	52·5
23	161·75	47·0	177·0	149·0	179·5	45·5	98·75	33·5	90·0
24	309·0	270·0	312·0	268·0	300·0	253·0	203·0	168·0	160·0
25	15·4	13·5	15·6	13·4	15·0	12·6	10·2	8·4	8·0
26	24·1	27·5	24·4	16·7	17·1	22·3	30·4	13·6	19·2
27	132	147	155	155	165	172	137	158	159
28	104	120	120	121	120	132	109	129	123
29	360	370	445	405	610	570	340	370	450
30	74	72	74	74	75	76	75	80	71
31	0·024	0·017	0·081	0·043	0·131	0·098	0·018	0·008	0·025
32	9·3	12·4	11·0	10·0	9·1	12·4	9·6	14·5	12·1
33	10·2	7·0	8·0	9·3	10·4	7·3	9·7	4·7	7·0
34	0·2	0·3	0·2	0·3	0·2	0·2	0·3	0·4	0·2
35	80·3	80·3	80·8	80·4	80·3	80·1	80·4	80·4	80·7
36	13·8	10·3	11·8	13·0	14·4	10·5	13·3	9·2	10·9
37	91·6	48·8	59·4	77·0	95·0	52·2	83·1	28·2	48·4
38	66800	69760	98250	98180	132870	127800	69900	81190	102500
39	6120	6120	5710	5820	5330	5330	6040	6090	5950
40	94·8	93·5	94·5	96·6	96·6	95·1	95·9	98·3	97·2
41	63·8	63·0	59·4	60·5	55·5	54·8	63·0	62·5	62·9
42	9600	9720	9620	9620	9600	9720	9600	9740	9470
43	6120	6120	5710	5820	5330	5330	6040	6090	5950
	63·8	63·0	59·4	60·5	55·5	54·8	63·0	62·5	62·9
44	580	570	580	570	630	610	600	590	610
	6·0	5·9	6·0	5·9	6·6	6·3	6·2	6·1	6·4
45	950	740	1050	1030	1850	1250	850	640	990
	9·9	7·6	10·9	10·7	19·3	12·9	8·8	6·6	10·4
46	570	700	600	370	370	520	460	180	300
	5·9	7·2	6·2	3·8	3·9	5·3	4·8	1·8	3·2
47	110	120	100	160	120	80	160	150	90
	1·2	1·2	1·0	1·7	1·2	0·8	1·7	1·5	0·9
48	1270	1470	1580	1670	1300	1930	1490	2090	1520
	13·2	15·1	16·5	17·4	13·5	19·9	15·5	21·5	16·2

Tests marked * have been discarded as not being representative of the fuel.

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Alberta Domestic No. 3				Alberta Domestic No. 4				Item No.
G-32-B	**G-74-B***	**G-38-B**	**G-69-B***	**G-37-A**	**G-31-A**	**G-31-B**	**G-37-B**	1
9-8-24	9-23-25	10-27-24	8-19-25	10-20-24	8-25-24	8-25-24	10-20-24	2
65	25	48	15	90	65	65	42	3
5	5	3	3	6	5	5	3	4
16·1	15·1	16·7	16·4	15·9	15·8	15·8	15·9	5
8·8	7·7	7·2	8·0	12·4	11·3	11·3	12·4	6
30·9	33·4	31·4	31·6	28·2	28·7	28·7	28·2	7
44·2	43·8	44·7	44·0	43·5	44·2	44·2	43·5	8
9470	9990	9600	9740	8960	9110	9110	8960	9
54·6	56·2	55·3	55·0	53·9	54·8	54·8	53·9	10
5·5	5·5	5·7	5·6	5·1	5·1	5·1	5·1	11
8·8	7·7	7·2	8·0	12·4	11·3	11·3	12·4	12
0·5	0·5	0·5	0·5	0·2	0·2	0·2	0·2	13
1·2	1·2	1·2	1·2	0·8	0·8	0·8	0·8	14
29·4	28·9	30·1	29·7	27·6	27·8	27·8	27·6	15
1118·0	417·0	1154·75	363·25	1034·75	1175·75	1168·5	1049·75	16
86·0	83·4	72·2	72·6	69·0	90·4	89·9	75·0	17
17·2	16·7	24·2	24·2	11·5	18·1	18·0	25·0	18
5·1	4·9	7·1	7·1	3·4	5·3	5·3	7·3	19
16·56	16·41	18·12	18·64	16·53	17·34	17·45	18·73	20
44·0	18·5	50·0	7·75	29·5	42·0	49·25	76·75	21
47·5	14·75	50·5	24·5	97·25	108·5	107·25	54·5	22
91·5	33·25	100·5	32·25	126·75	150·5	156·5	131·25	23
164·0	159·0	174·0	177·0	245·0	256·0	268·0	250·0	24
8·2	8·0	8·7	8·9	12·2	12·8	13·4	12·5	25
15·2	19·4	22·6	29·4	15·3	14·1	15·7	13·0	26
160	158	177	175	135	164	163	181	27
124	121	123	134	109	128	129	124	28
405	470	565	520	365	455	410	640	29
71	71	77	83	73	78	78	74	30
0·019	0·078	0·102	0·063	0·027	0·043	0·045	0·137	31
11·1	12·8	10·1	13·3	9·5	11·4	9·9	9·2	32
7·6	6·6	9·3	6·4	9·7	7·7	9·5	10·1	33
0·6	0·1	0·3	0·2	0·3	0·3	0·3	0·3	34
80·7	80·5	80·3	80·1	80·5	80·6	80·3	80·4	35
11·5	10·8	12·9	9·9	13·3	11·4	13·0	13·8	36
54·9	44·6	77·2	43·0	82·9	56·1	80·2	89·6	37
103900	101500	132770	129930	69580	104300	102920	133520	38
6040	6090	5520	5370	6050	5770	5730	5340	39
97·9	97·6	97·2	95·6	96·9	97·4	97·1	97·4	40
63·8	61·0	57·5	55·1	67·5	63·3	62·9	59·6	41
9470	9990	9600	9740	8960	9110	9110	8960	42
6040	6090	5520	5370	6050	5770	5730	5340	43
63·8	61·0	57·5	55·1	67·5	63·3	62·9	59·6	
600	600	650	630	540	560	550	600	44
6·3	6·0	6·8	6·5	6·0	6·1	6·0	6·7	
920	900	1510	1040	930	1030	1040	1870	45
9·7	9·0	15·7	10·7	10·4	11·3	11·4	20·9	
230	270	310	480	330	180	310	270	46
2·4	2·7	3·2	4·9	3·7	2·0	3·4	3·0	
280	40	160	80	160	140	160	170	47
3·0	0·4	1·7	0·8	1·8	1·5	1·8	1·9	
1400	2090	1450	2140	950	1430	1320	710	48
14·8	20·9	15·1	22·0	10·6	15·8	14·5	7·9	

TABLE VI—Continued

Detailed Data and Results of All Tests—Continued

Item No.	Alberta Domestic No. 5							Welsh Bri-quettes	Air-dried Machine peat	
1	**G-36-A**	**G-64-B***	**G-74-A***	**G-30-A**	**G-30-B**	**G-36-B**	**G-63-B***	**G-25-A***	**G-78-A***	**G-83-A**
2	10-13-24	6-22-25	9-23-25	8-18-24	8-18-24	10-13-24	6-17-25	2-25-24	10-21-25	12-29-25
3	90½	102½	18	66	65	39½	42	96	30	30
4	6	6	6	5	5	3	3	8	5	2½
5	19·6	19·3	17·3	19·1	19·1	19·1	18·8	1·3	32·0	25·1
6	9·1	7·9	9·7	8·4	8·4	9·1	8·5	10·2	4·3	4·4
7	31·5	32·2	32·1	32·1	32·1	31·5	32·1	12·4	43·1	47·0
8	39·8	40·6	40·9	40·4	40·4	39·8	40·6	76·1	20·6	23·5
9	8700	8880	9020	8840	8840	8700	8860	13380	6630	7350
10	51·6	52·7	52·8	52·5	52·5	51·6	52·6	....	38·7	42·8
11	5·7	5·7	5·5	5·7	5·7	5·7	5·6	....	7·4	7·0
12	9·1	7·9	9·7	8·4	8·4	9·1	8·5	....	4·3	4·4
13	0·2	0·3	0·2	0·3	0·3	0·2	0·3	1·0	0·1	0·2
14	1·0	1·0	1·0	1·0	1·0	1·0	1·0	....	1·1	1·2
15	32·4	32·4	30·8	32·1	32·1	32·4	32·0	....	48·4	44·4
16	1175·0	1340·75	218·0	1224·0	1203·0	1024·0	1059·75	840·0	601·5	592·5
17	78·0	78·9	72·7	87·5	92·5	78·8	75·7	64·6	100·2	49·4
18	13·0	13·1	12·1	17·5	18·5	25·9	25·2	8·8	20·0	19·7
19	3·8	3·9	3·5	5·1	5·4	7·6	7·4	2·6	5·9	5·8
20	18·73	19·69	18·07	18·90	19·19	19·42	21·65	12·18	29·43	25·00
21	12·5	17·25	0·0	32·0	30·25	34·25	28·0	....	0·0	0·0
22	114·5	178·75	16·0	112·5	100·75	56·0	119·25	157·25	25·5	23·5
23	127·0	196·0	16·0	144·5	131·0	90·25	147·25	157·25	25·5	23·5
24	216·0	292·0	147·0	236·0	218·0	176·0	278·0	374·0	85·0	79·0
25	10·8	14·6	7·3	11·8	10·9	8·8	13·9	18·7	4·2	4·0
26	32·4	47·0	43·7	30·6	30·3	21·4	43·2	49·3	23·4	16·7
27	139	142	136	158	160	178	163	126	126	123
28	112	113	109	123	122	128	121	95	97	92
29	375	350	320	450	400	600	525	290	330	325
30	73	71	72	73	73	74	73	....	72	68
31	0·026	0·033	0·052	0·057	0·051	0·098	0·100	0·036	0·039	0·037
32	8·9	11·4	9·3	12·1	12·3	10·5	10·9	....	6·5	10·9
33	9·9	8·0	11·2	7·0	6·9	8·5	8·5	....	14·1	8·9
34	0·4	0·3	0·1	0·3	0·4	0·4	0·5	....	0·1	0·2
35	80·8	80·3	79·4	80·6	80·4	80·6	80·1	....	79·3	80·0
36	13·0	10·2	12·6	10·1	9·9	11·4	10·5	....	14·2	9·6
37	85·6	59·9	113·0	48·5	47·7	65·8	66·4	....	202·0	72·0
38	69350	66440	67020	98120	96420	133500	116480	71870	68080	78980
39	5340	5080	5530	5290	5210	5150	4620	8210	3400	4000
40	93·9	90·4	89·7	94·9	95·0	96·5	91·1	88·8	97·9	98·8
41	61·4	57·2	61·3	59·8	58·9	59·2	52·1	61·4	51·3	54·4
42	8700	8880	9020	8840	8840	8700	8860	13380	6630	7350
43	5340	5080	5530	5290	5210	5150	4620	8210	3400	4000
	61·4	57·2	61·3	59·8	58·9	59·2	52·1	61·4	51·3	54·4
44	610	600	580	630	610	660	630	....	780	740
	7·0	6·8	6·4	7·1	6·9	7·6	7·1	....	11·8	10·1
45	940	680	750	910	780	1440	1140	....	880	590
	10·8	7·6	8·3	10·3	8·8	16·6	12·9	....	13·3	8·0
46	630	1020	1090	540	530	360	940	1440	190	130
	7·2	11·5	12·1	6·1	6·0	4·1	10·6	10·8	2·9	1·8
47	210	120	50	120	160	180	210	....	60	80
	2·4	1·4	0·6	1·4	1·8	2·1	2·4	....	0·9	1·1
48	970	1380	1020	1350	1550	910	1320	....	1320	1810
	11·2	15·5	11·3	15·3	17·6	10·4	14·9	....	19·8	24·6

Tests marked * have been discarded as not being representative of the fuel.

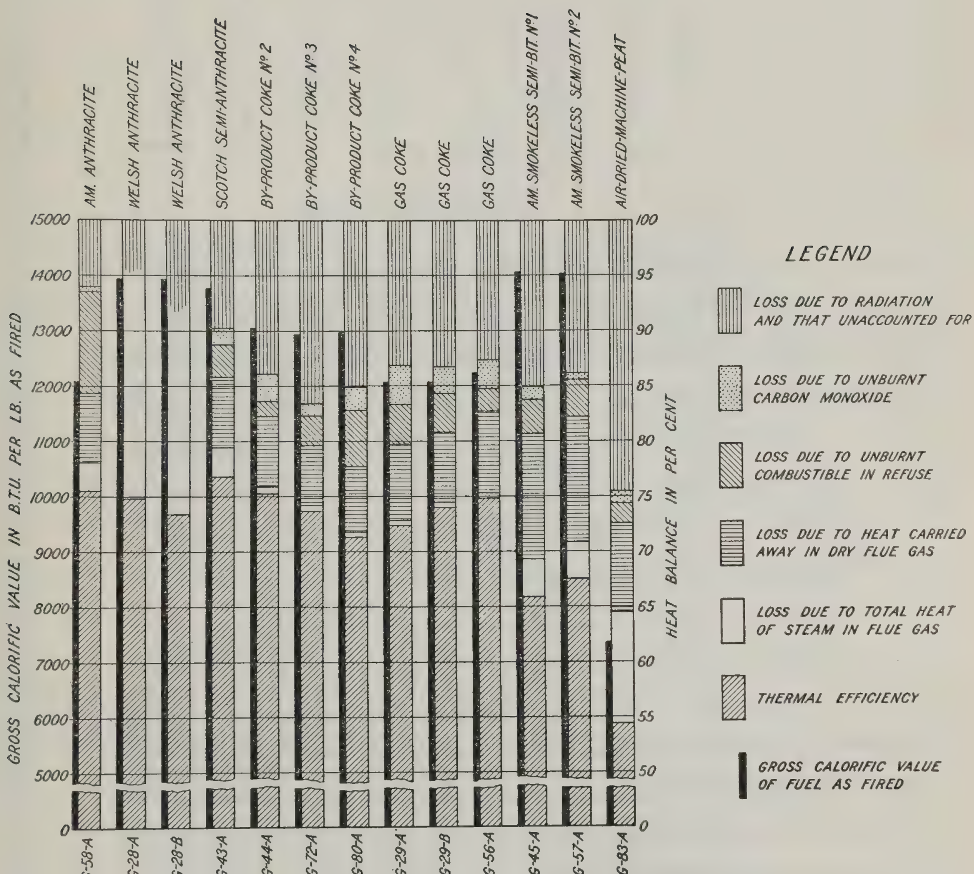


Chart I.—Chart showing calorific values, thermal efficiencies, and heat losses of the anthracites, cokes, and American smokeless, semi-bituminous coals, and peat tested at a load of approximately 66,000 B.T.U. per hour.

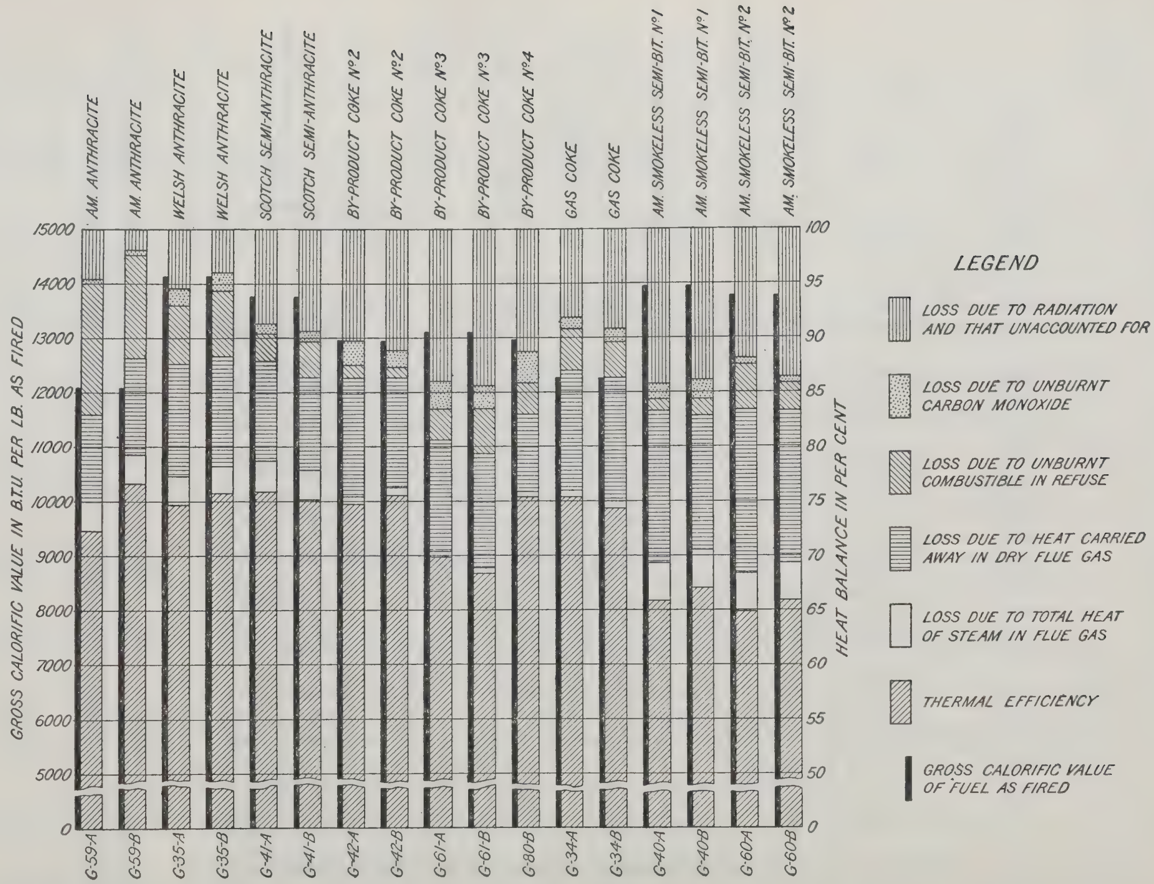


Chart II.—Chart showing calorific values, thermal efficiencies, and heat losses of the anthracites, cokes, and American smokeless, semi-bituminous coals tested at a load of approximately 99,000 B.T.U. per hour.

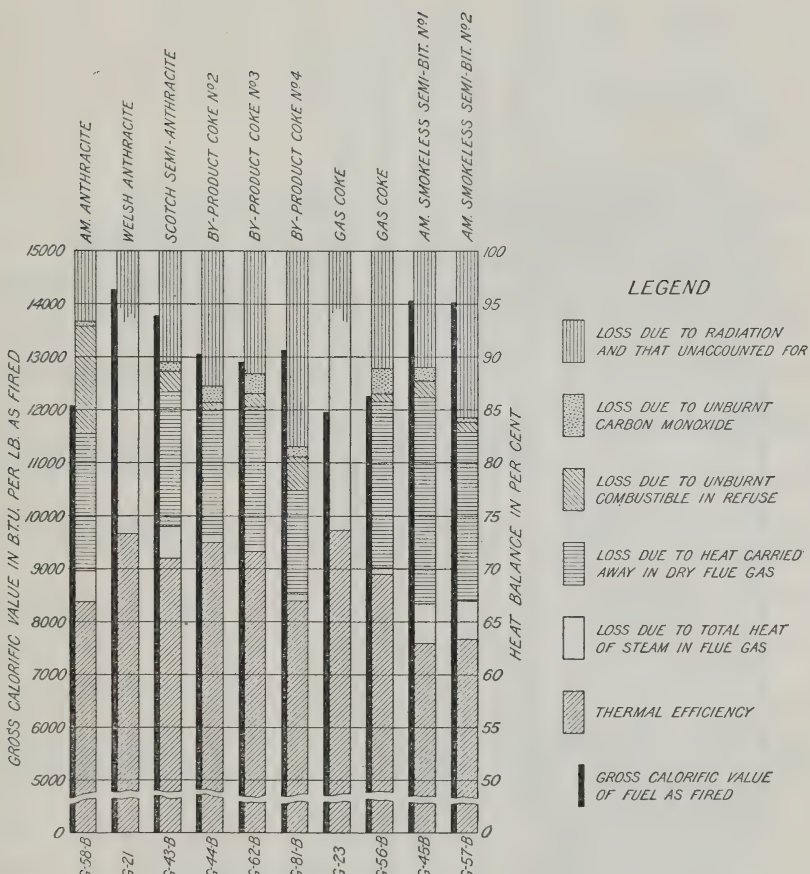


Chart III.—Chart showing calorific values, thermal efficiences, and heat losses of the anthracites, cokes, and American smokeless, semi-bituminous coals tested at a load of approximately 132,000 B.T.U. per hour.

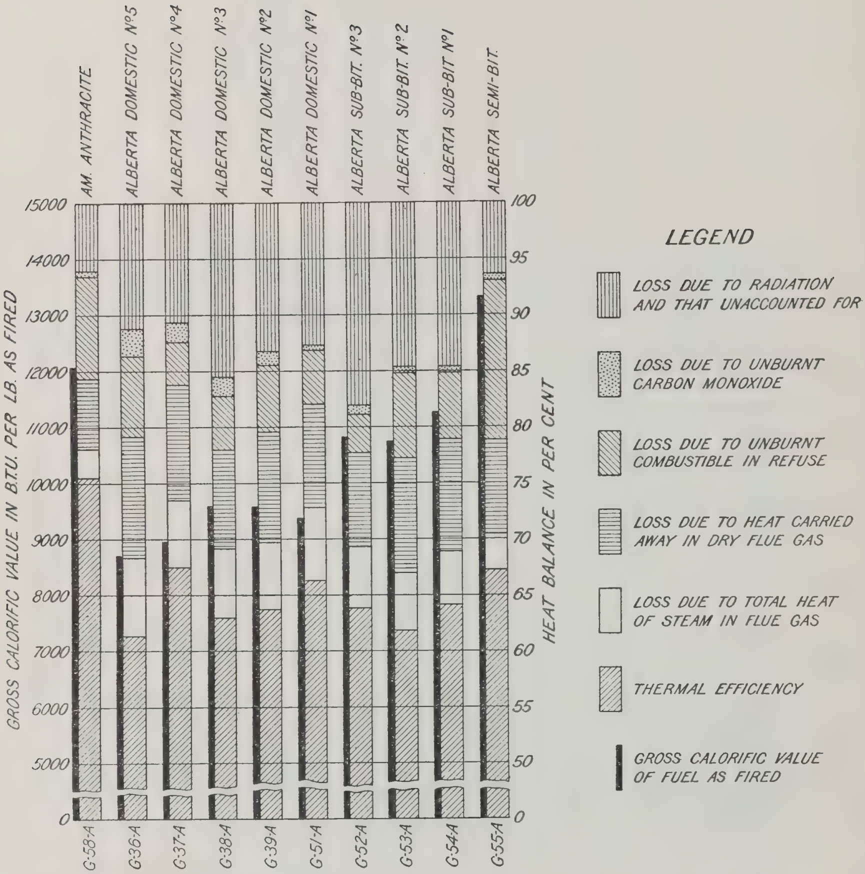


Chart IV.—Chart showing calorific values, thermal efficiencies, and heat losses of American anthracite and the Alberta coals tested at a load of approximately 66,000 B.T.U. per hour.

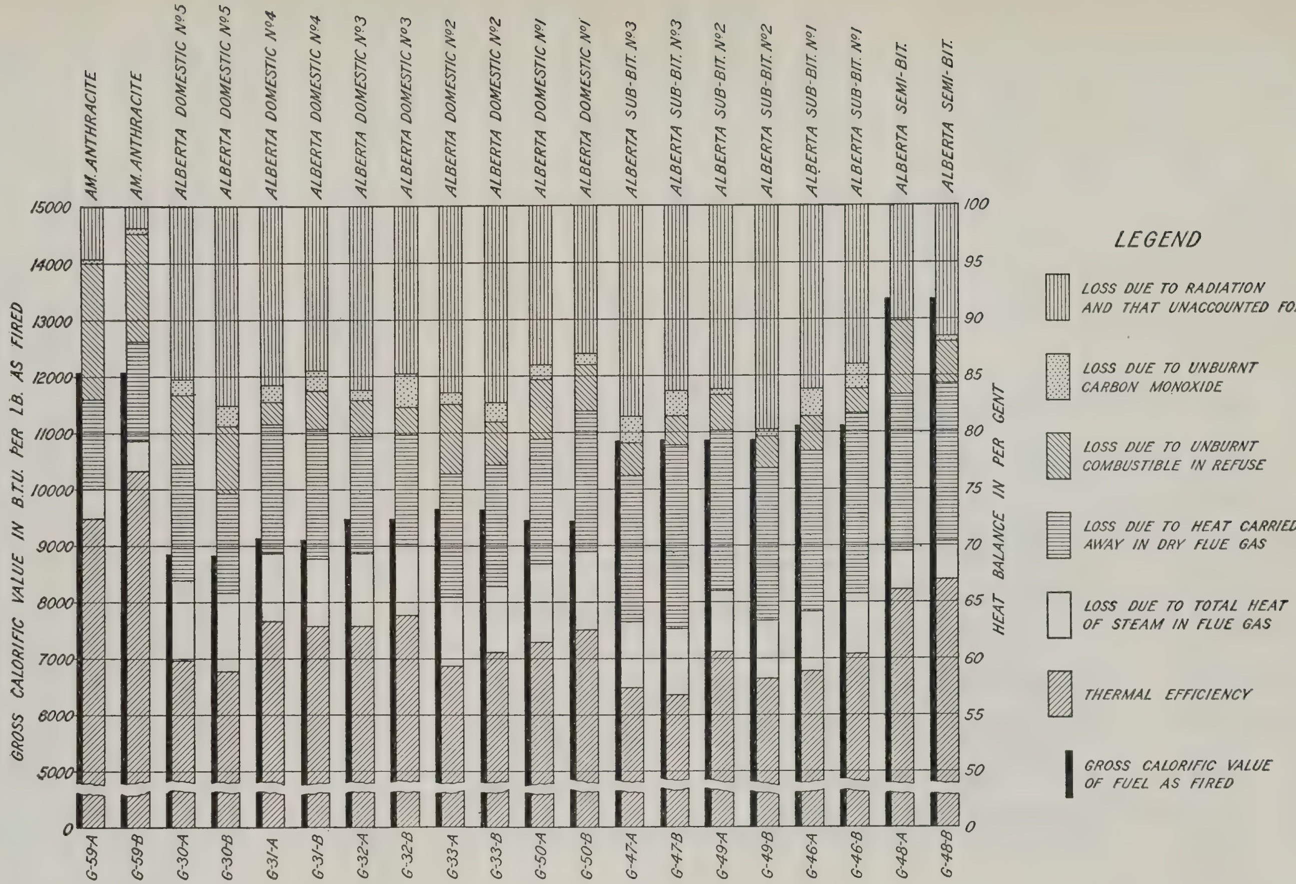


Chart V.—Chart showing calorific values, thermal efficiencies, and heat losses of American anthracite and the Alberta coals tested at a load of approximately 99,000 B.T.U. per hour.

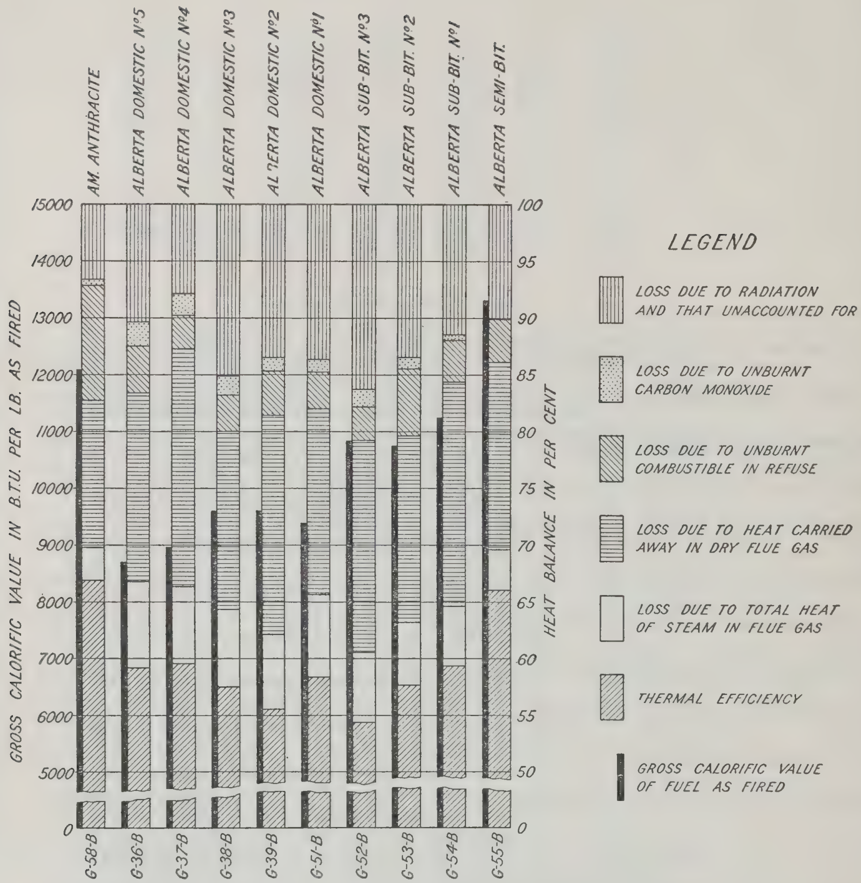


Chart VI.—Chart showing calorific values, thermal efficiencies, and heat losses of American anthracite and the Alberta coals tested at a load of approximately 132,000 B.T.U. per hour.

DISCUSSION OF RESULTS

Table VI gives the results in detail of the 123 tests which were made on tweny-one different fuels. This table gives proximate and ultimate analyses of each fuel; quantity of fuel fired and refuse removed; temperature and draught observations; analyses of the flue gases; economic results; as well as the heat balance for the majority of the tests. It will be noted that flue gas analyses were not made for the earlier tests; this was on account of the limited staff then available to act as observers.

Item 20, *quantity of fuel fired per therm (100,000 B.T.U.) delivered to the cooling water*, is the most important item in the table, as it is a measure of the quantity of fuel fired per unit of useful heat delivered, and is used in

comparing one fuel with another, in preference to the item giving the overall thermal efficiency.

Item 3, *duration of test*, shows that the majority of tests were from 39½ to 120 hours in length. These tests were the "long tests" in which approximately 1,000 pounds of fuel were burned. The remaining tests, having a duration of from 16 to 32 hours, were the "short tests" in which the total fuel fired was approximately 250 pounds.

In working up the results it became evident that the short tests did not give the required accuracy. Accordingly, all short tests were discarded with the exception of one test on air-dried, machine peat, one on by-product coke No. 3, and those on by-product coke No. 4. Long tests which were found to be in gross error in one particular or another, were also discarded. The discarded tests are marked with an asterisk in Table VI and the results of these tests were not used in the compilation of other tables, charts, and diagrams, with the exception of Tables IV, V, and IX.

Knowing the various factors that go to make up the general suitability of a solid fuel for domestic purposes, discussion based on these factors giving specific comparisons arranged in the order of merit of the various fuels, should logically follow; and although it was the original intention to investigate these various factors in order to make a comparison of the fuels, it was found practical only to measure directly the quantity of fuel fired per therm of useful heat delivered from which the overall thermal efficiency could be obtained. Therefore, discussion other than that directly based on the specific results obtained must of necessity be quite general, as the chief factor that was directly and accurately measured by this series of tests was that of fuel fired per term delivered, and hence, it is on this factor alone that any direct comparison can be made, one fuel with another.

Although *the quantity of fuel fired per therm delivered* is one of the most important factors in the comparison of fuels, it is by no means the only important one when the fuels are being compared for house heating purposes. Careful observation and notation of general data during each test was the only feasible way of obtaining a comparison of the other factors, without extending the tests especially to investigate each of them separately. At the conclusion of the tests a comparison was made, test with test, so that some idea of the relative value of each fuel in relation to the other factors under consideration could be obtained. Unfortunately, the personal element entered to a large degree into any comparisons that were made, as the general observations and notes made were dependent absolutely on the personnel. The many changes in the staff of observers and the necessary interpretation of the general notes by a different individual from those making the notes further complicated matters. Any comparison of the factors that were determined by general observation, excepting such as were determined by measured data, must necessarily represent only the viewpoint of the individual making or interpreting the notes.

Data such as duration of tests, length of fire-period, chemical analysis, amounts of fuel fired, flue gas analysis, etc., have been fully commented upon in other parts of this report and therefore require no further discussion under this head. The discussion which follows is more particularly limited to overall thermal efficiency, quantity of fuel fired per therm delivered, and the various heat losses that help to make up the heat balance; along with discussion on the fuels tested, and the economic results obtained.

OVERALL THERMAL EFFICIENCY

Overall thermal efficiency or the so-called "efficiency of heat transference" may be defined as the amount of useful heat available for heating the house, expressed as a percentage of the heat in the fuel as fired. It is the principal item of any heat balance that may be made, and considered with the heat losses is a valuable indication of how efficiently the furnace was operated. Although item 40 in Table VI gives the efficiencies obtained for each test made, in order to facilitate a more critical study of the thermal efficiencies Table VII has been made up to show the limiting values and averages of the efficiencies obtained with each fuel.

TABLE VII

Showing Average Values for the Fixed Carbon and Volatile Matter Content of the Fuels and the Variation in the Overall Thermal Efficiency for the Accepted Tests

Fuel	Number of accepted tests	Average values		Overall thermal efficiency		
		Fixed carbon %	Volatile matter %	Low value	High value	Average value
Anthracites—						
1. American	4	75·5	6·2	66·9	76·6	72·8
2. Welsh	5	85·1	7·8	73·3	75·7	74·4
3. Scotch semi-	4	80·1	10·0	71·0	76·8	74·7
Average	....	80·2	8·0	70·4	76·4	74·0
Cokes—						
4. Gas	7	85·2	1·9	69·5	75·4	73·4
6. By-product No. 2	4	89·6	1·7	72·5	75·5	74·5
7. By-product No. 3	4	90·5	1·6	68·4	73·6	70·9
8. By-product No. 4	3	90·7	1·6	67·0	75·4	71·2
Average	....	89·0	1·7	69·4	75·0	72·5
Semi-bituminous Coals—						
9. American smokeless No. 1	4	70·9	19·8	63·0	67·0	65·4
10. American smokeless No. 2	4	72·7	15·8	63·4	67·5	65·4
11. Alberta	4	70·1	15·8	66·0	67·2	66·6
Average	....	71·2	17·1	64·1	67·2	65·8
Alberta Coals—						
12. Sub-bituminous No 1	4	50·4	32·4	58·9	64·1	60·7
13. Sub-bituminous No. 2	4	47·1	34·3	57·6	61·9	59·6
14. Sub-bituminous No. 3	4	46·7	32·7	54·4	63·9	58·1
15. Domestic No. 1	4	43·4	30·2	58·4	66·3	62·2
16. Domestic No. 2	4	42·8	31·9	55·5	63·8	59·8
17. Domestic No. 3	4	44·5	31·2	57·5	63·8	61·8
18. Domestic No. 4	4	43·9	28·5	59·6	67·5	63·3
19. Domestic No. 5	4	40·1	31·8	58·9	61·4	59·8
Average	....	44·9	31·6	57·6	64·1	60·7
Special Fuels—						
21. Air-dried, machine peat	1	23·5	47·0	54·4	54·4	54·4

The above table shows that the efficiencies divide themselves into three main groups. Group No. 1, consisting of the anthracite and coke fuels, gave values of over 70 per cent; group No. 2, consisting of the semi-

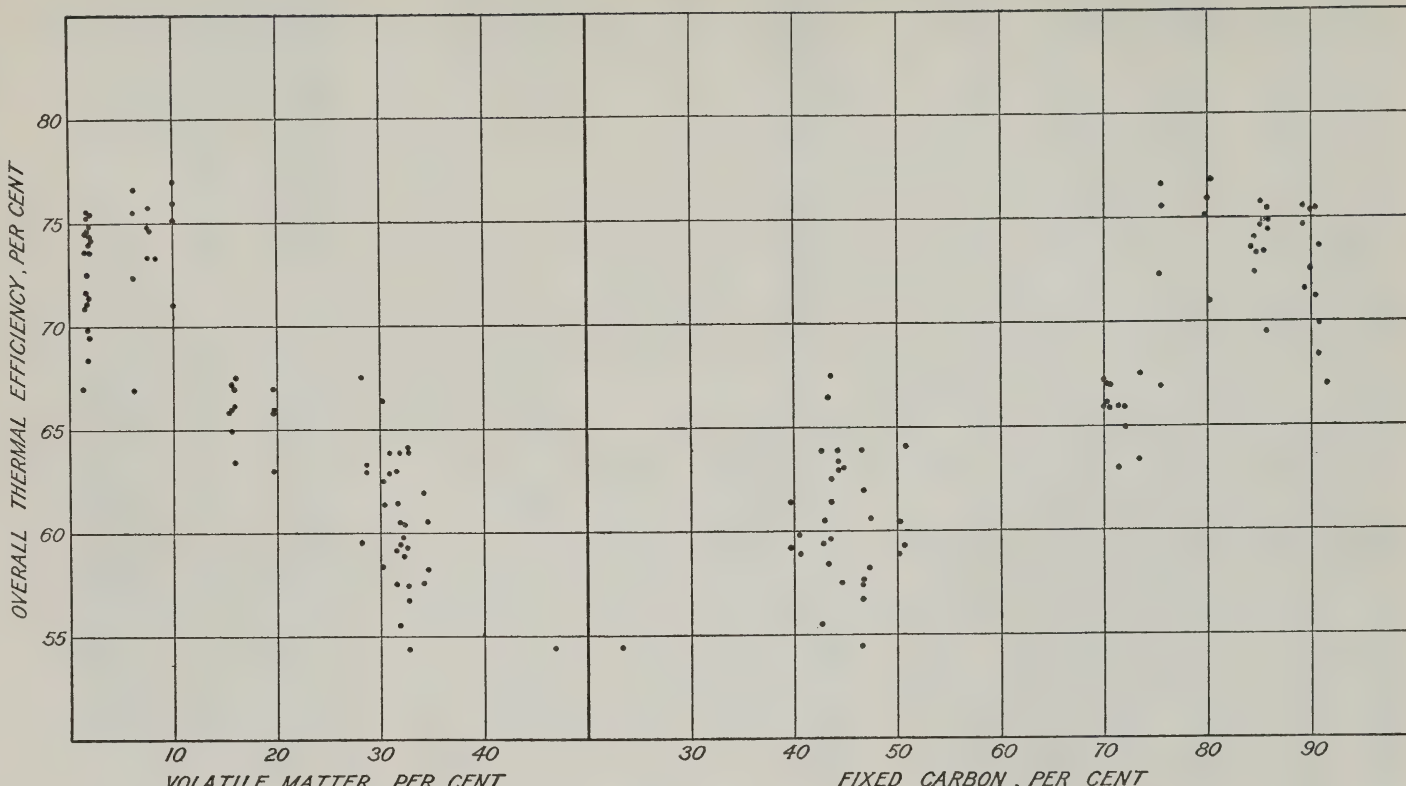


Figure 2.—Graph showing the relation between overall thermal efficiency and volatile matter, and overall thermal efficiency and fixed carbon.

bituminous coals, gave values around 65 per cent; while group No. 3, consisting of the Alberta sub-bituminous and domestic coals, gave values around 60 per cent. The conclusion, therefore, was that some inherent characteristic of the fuel determines to a certain degree the efficiency obtained, and it was thought that the fixed carbon or volatile matter content of the fuel had a decided bearing on the matter.

In Figure 2 the overall thermal efficiencies are plotted as ordinates on a base representing the volatile matter and fixed carbon content of the fuel. The diagram shows definitely that high efficiency was obtained with such fuels as were high in fixed carbon content and consequently low in volatile matter content and vice versa. Generally then, it may be assumed that higher efficiency will result when burning a fuel high in fixed carbon content, where combustion is completed in or close to the fuel bed, than when burning a fuel high in volatile matter content, which when burning gives off a great amount of combustible gas that may or may not be burned. The position of the points on the diagram plainly show that the furnace was much better suited for operation on the low volatile fuels than on the high ones. The points lie in four approximate groups: one for the cokes, which have the lowest volatile matter content; and the rest in the following order, the anthracites, the semi-bituminous coals, and the high volatile Alberta fuels. The irregular relationship of the points derived from the coke and anthracite tests shows in a general way that the furnace was better suited for burning anthracite than for burning coke; and, further, the unsuitability of this type of furnace for burning the Alberta fuels is clearly demonstrated.

As the fuels were all tested in the same furnace and in a similar manner, with the exception only that the method of firing the fuel and controlling the fire was altered to suit the physical characteristics of the three groups of fuels. For instance, the method of firing the Alberta fuels was very different from the method adopted when testing the anthracites and cokes, and in a similar way the method adopted when testing the semi-bituminous coals was different in its turn from the other two. It may be safely stated then that the differences in thermal efficiencies were due to a certain extent to the fact that all the various fuels were tested in the same furnace, whereas had the coals been burned in furnaces designed for each particular kind of fuel, the results would have been very different and the thermal efficiencies would in all probability be found to be more alike.

VARIATIONS IN EFFICIENCY

Examination of item 41, Table VI, will show that the efficiencies obtained varied over a considerable range. Excluding peat, which is not a coal fuel, the efficiencies vary from 54·4 per cent with Alberta sub-bituminous coal No. 3, to 76·8 per cent with Scotch semi-anthracite, a range of 22·4 per cent.

Variations in efficiency may be due to a number of factors, chief of which are:—

(1) Size, type, and quality of apparatus.
(2) Methods employed in operating the apparatus.
(3) Type and quality of the fuel used.
(4) Fire conditions prevailing during the test.

Therefore, any comparison of the efficiencies of the different tests should be made with the greatest care, not only for tests conducted on different fuels but also between tests made on the same fuel.

The two boilers employed for the work were not only identical as to size, type, and manufacture, but were installed together with the necessary auxiliary apparatus in an exactly similar manner; and, furthermore, the methods employed in conducting the tests were similar. Therefore, no material difference in efficiency should result from either the apparatus in use or the methods used in operation of this apparatus when testing the same fuel and such factors as relate to apparatus and method of use may be omitted, as the purpose was to make a comparison between fuels, which comparison should place the fuels in the same order as to merit as long as the tests are made in a similar manner and in like apparatus.

In those tests where the boilers were operated simultaneously on the same fuel and at the same load, the range in efficiency between these tests varied only slightly, as can be seen by Table VIII following. As apparatus, method of operation, and fuel were constant, such variation as is shown was due, no doubt, to slight differences which developed in fire conditions during the course of these tests.

TABLE VIII

Comparison of Efficiencies between Tests Conducted Simultaneously on the Same Fuel, at the Same Load, under like Operating Conditions and in like Boilers, showing that the Variation in Efficiency between the Two Units is Small and Well within the Range of Experimental Error

Fuel	Approximate heat delivery in 1,000 B.T.U. per hour	Boiler Unit "A"		Boiler Unit "B"		Variation in thermal efficiency
		Test No.	Thermal efficiency	Test No.	Thermal efficiency	
Anthracites—						
1. American	99	G-59-A	72·3	G-59-B	76·6	4·3
2. Welsh	99	G-35-A	74·7	G-35-B	75·7	1·0
2. Welsh	66	G-28-A	74·8	G-28-B	73·4	1·4
3. Scotch semi-	99	G-41-A	75·9	G-41-B	75·1	0·8
Cokes—						
4. Gas	99	G-34-A	75·4	G-34-B	74·4	1·0
4. Gas	66	G-29-A	72·3	G-29-B	74·0	1·7
6 By-product No. 2	99	G-42-A	74·7	G-42-B	75·5	0·8
7. By-product No. 3	99	G-61-A	69·9	G-61-B	68·4	1·5
Semi-bituminous Coals—						
9. American Smokeless No. 1	99	G-40-A	65·8	G-40-B	67·0	1·2
10. American Smokeless No. 2	99	G-60-A	64·9	G-60-B	65·9	1·0
11. Alberta	99	G-48-A	66·1	G-48-B	67·0	0·9
Alberta Coals—						
12. Sub-bituminous No. 1	99	G-46-A	58·9	G-46-B	60·4	1·5
13. Sub-bituminous No. 2	99	G-49-A	60·6	G-49-B	58·2	2·4
14. Sub-bituminous No. 3	99	G-47-A	57·4	G-47-B	56·7	0·7
15. Domestic No. 1	99	G-50-A	61·4	G-50-B	62·5	1·1
16. Domestic No. 2	99	G-33-A	59·4	G-33-B	60·5	1·1
17. Domestic No. 3	99	G-32-A	62·9	G-32-B	63·8	0·9
18. Domestic No. 4	99	G-31-A	63·3	G-31-B	62·9	0·6
19 Domestic No. 5	99	G-30-A	59·8	G-30-B	58·9	0·9

The variations in type and quality of the fuel and the fire conditions prevailing during the course of a test must then be the factors that are responsible for the variation in efficiency between the limits as given in Table VIII. For the tests here considered it is believed that the decided differences in efficiency were caused by various fire conditions due to the size of fuel burned and to the amount of fine material it contained, to the degree with which the fire bed coked, burned evenly over the grate, and also, to the extent to which the gases first distilled from a fresh charge of fuel were burned or passed away unconsumed. While efforts were made throughout the tests to keep fire conditions uniform, such variations as did occur point to the possibility of improving efficiency by proper attention to such details as relate to fuel, operation, and equipment.

THERMAL EFFICIENCY AS INFLUENCED BY LOAD ON BOILER

The conditions under which house-heating boilers operate are so varied that it is impossible to state at what percentage of their rated capacity they ordinarily operate and therefore it would be impossible to follow these variations under test conditions. A boiler used for heating an office building, school house, or for work of a similar character might be operated at a relatively high rated capacity for a considerable portion of the day, while in house installations the boiler may only be required to operate at a high capacity for a few hours each day and the average load may not be more than 20 per cent of the rated capacity, and it would be expected that the efficiencies obtainable in practice would be influenced to a certain degree by the uneven and, for most of the time, the low combustion rate at which house-heating apparatus is operated.

The opinion is held by many that the efficiencies that may be obtained with a house-heating boiler are of a low order. The results obtained in this series of tests are, therefore, remarkable in that they show that the efficiencies compare very favourably with those which are obtained in small commercial or power boiler installations

The boilers were operated at three loads, corresponding approximately to rates of heat delivery of 66,000 B.T.U. per hour, 99,000 B.T.U. per hour, and 132,000 B.T.U. per hour; these figures correspond to boiler horsepowers of approximately 2, 3, and 4 respectively. The boilers used in this investigation each had a heating surface of 32·4 square feet and if these boilers are rated at 10 square feet of heating surface per boiler horsepower, it will be seen that the rate of combustion to produce the necessary transference of heat must be high and as high as is usual in average small power boiler installations. The variable demand upon the house-heating boiler will at times necessitate very high or very low rates of heat transference per square foot of heating surface, and the nature of the service may readily warrant somewhat inefficient performance under these conditions, in order that the equipment be comparatively inexpensive, simple in construction, and easily operated. From the tests made during this investigation it may be noted that it is inadvisable to operate a house-heating boiler at such high rates as are found economical in power boiler work and if house-heating boilers are operated at such high rates it is impossible to obtain the highest efficiencies. The effort should be made to so

adapt the fuel and equipment that a rate of heat transference would be obtained which under average operating conditions would be most apt to be accompanied by high efficiency.

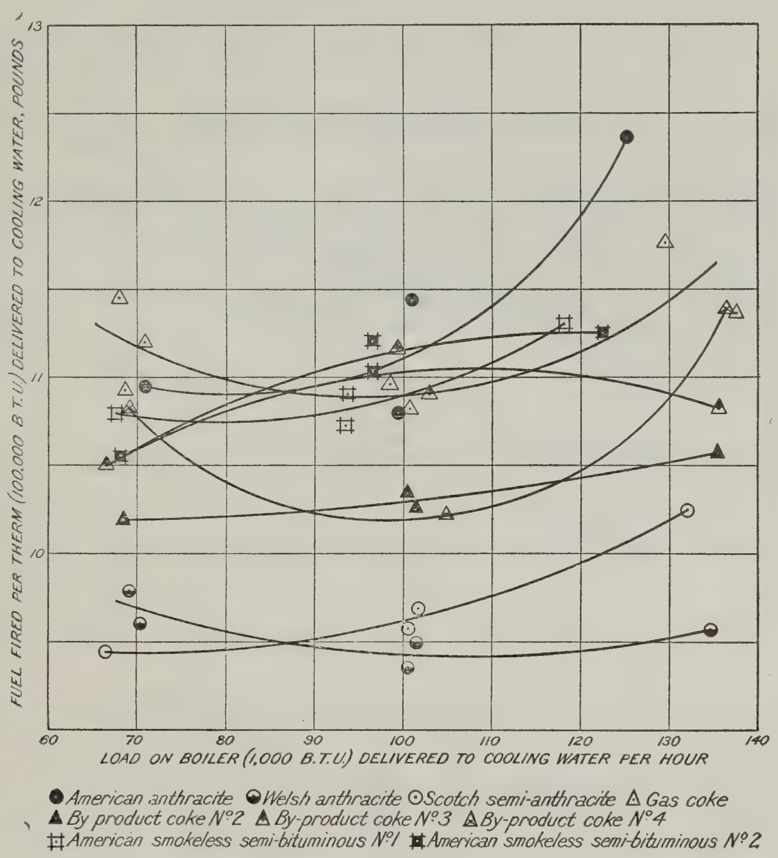


Figure 3.—Graph showing the relation between fuel fired per therm of heat delivered and load on boiler for the anthracites, cokes, and American smokeless, semi-bituminous coals.

Figure 3 is a graph showing the relation between the quantity of fuel fired per therm delivered and the load on the boiler for the anthracites, cokes, and American smokeless, semi-bituminous coals. From this graph it would appear that it is more economical to operate this type of furnace with these fuels at low and intermediate loads than at high load. In general, little difference can be noted between low and intermediate loads, as some fuels show the operation at intermediate load to be more economical than at low load, and with the rest, vice versa, but in no case was the operation of the furnace more economical at high load than at either of the other two.

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Figure 4 is a graph showing the relation between the quantity of fuel fired per therm delivered and the load on the boiler for American anthracite and all the Alberta fuels. It will be noted first that it takes from

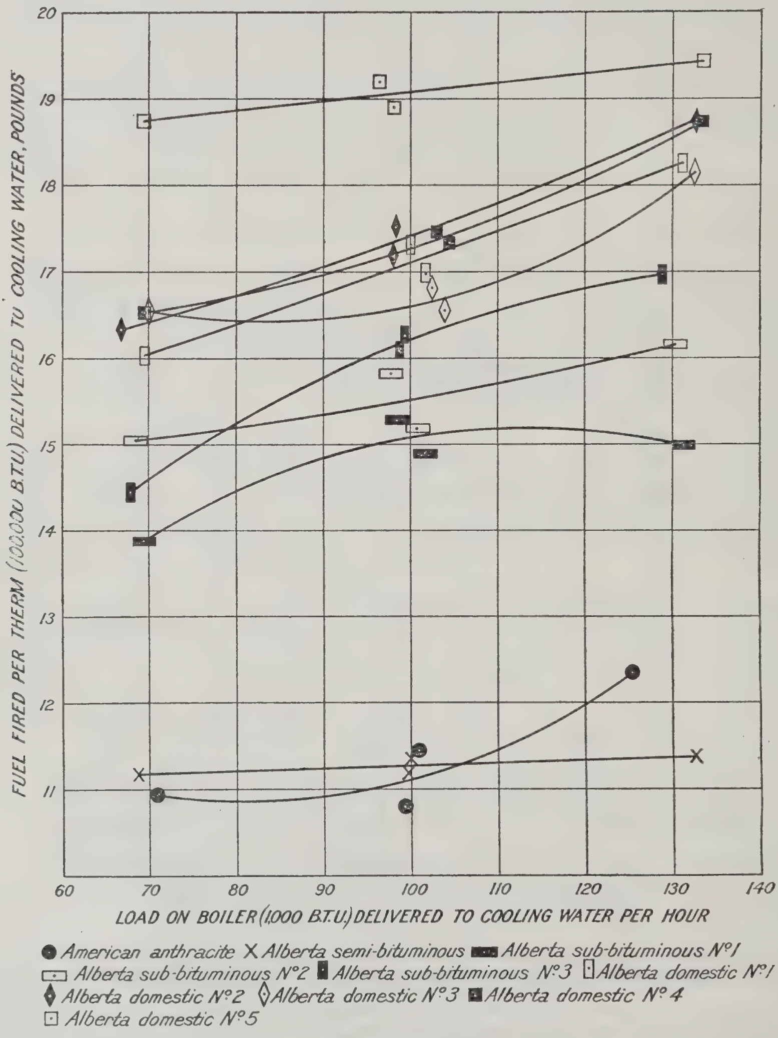

Figure 4.—Graph showing the relation between fuel fired per therm of heat delivered and load on boiler for all the Alberta coals and American anthracite.

25 to 65 per cent more fuel to deliver the same quantity of heat when burning any of the Alberta fuels, with the exception of Alberta semi-bituminous coal, than it does when burning American anthracite; and

second, it is much more economical to operate the furnace at low load when burning the Alberta fuels than at either intermediate or high load. This point is shown very clearly by the curves, which all slope up from left to right. From these curves it is seen that Alberta semi-bituminous coal is the equal of American anthracite, when compared on the basis of quantity of fuel fired per therm delivered.

DISTRIBUTION OF HEAT LOSSES

Items 44 to 48 inclusive in Table VI give the various heat losses for all tests on which flue gas analyses were made, and Table IX which has been abstracted from Table VI gives a comparison of the high, low, and average value of these losses for the various fuels tested. Close examination of these items shows that the values obtained for the losses are quite consistent when the difficulty of obtaining accurate and representative analysis is considered.

TABLE IX

Comparison of the Heat Losses giving the Low, High, and Average Values for the Various Fuels Tested

–	Fuel	Per cent loss due to														
		(1) Steam formed, etc.			(2) Heat carried away in dry flue gases			(3) Unburned combustible matter in refuse			(4) Unburned carbon monoxide			(5) Balance of heat account, etc.		
		Low value	High value	Average value	Low value	High value	Average value	Low value	High value	Average value	Low value	High value	Average value	Low value	High value	Average value
1	American anthracite	2·6	2·9	2·7	6·3	12·9	9·0	9·1	12·0	10·2	0·4	0·5	0·5	1·9	6·6	4·5
2	Welsh anthracite	2·5	2·6	2·6	10·1	10·3	10·2	3·4	6·1	5·7	1·6	1·6	1·6	4·0	5·4	4·7
3	Scotch semi-anthracite	2·7	3·0	2·8	6·3	12·6	9·2	2·0	3·3	2·7	0·9	1·4	1·0	8·7	10·5	9·6
4	Gas coke	0·5	0·6	0·6	6·3	15·6	9·8	0·8	3·8	2·9	1·1	3·6	2·2	8·1	13·3	11·2
6	By-product coke No. 2	0·6	0·7	0·7	6·4	11·7	9·8	0·8	1·4	1·1	1·5	2·4	1·9	10·3	13·9	12·0
7	By-product coke No. 3	0·5	0·6	0·5	5·5	13·0	9·8	1·3	2·9	2·8	1·1	2·5	1·9	11·6	16·6	14·2
8	By-product coke No. 4	0·5	0·6	0·5	5·9	9·8	7·6	2·9	5·1	3·7	1·0	2·8	2·0	11·3	18·5	15·0
9	American smokeless, semi-bituminous No. 1	3·4	3·7	3·6	11·3	19·4	14·3	1·5	3·1	2·2	1·2	1·7	1·4	11·0	15·1	13·3
10	American smokeless, semi-bituminous No. 2	3·3	3·6	3·5	11·3	15·8	14·0	1·0	4·1	2·8	0·5	0·6	0·6	11·9	15·7	13·8
11	Alberta semi-bituminous	3·2	3·6	3·4	8·4	16·5	13·2	3·7	14·2	7·0	0·0	0·6	0·3	6·4	11·5	9·6
12	Alberta sub-bituminous No. 1	4·8	5·3	5·2	10·0	19·8	15·0	2·2	5·9	3·7	0·5	2·4	1·4	11·5	16·2	14·1
13	Alberta sub-bituminous No. 2	5·1	5·6	5·3	10·2	16·4	13·5	2·8	7·6	4·9	0·5	1·0	0·7	13·5	19·8	16·0
14	Alberta sub-bituminous No. 3	5·5	6·1	5·8	8·3	18·7	14·0	2·6	3·4	3·0	0·9	2·3	1·8	16·3	18·7	17·4
15	Alberta domestic No. 1	6·6	7·2	6·9	9·2	16·4	12·3	3·2	5·2	4·3	0·5	1·3	1·0	12·6	14·1	13·4
16	Alberta domestic No. 2	5·9	6·6	6·1	9·9	19·3	12·7	3·8	6·2	5·0	1·0	1·7	1·3	13·2	17·4	15·2
17	Alberta domestic No. 3	6·2	6·8	6·4	8·8	15·7	11·2	2·4	4·8	3·4	0·9	3·0	1·8	14·8	16·2	15·4
18	Alberta domestic No. 4	6·0	6·7	6·2	10·4	20·9	13·5	2·0	3·7	3·0	1·5	1·9	1·8	7·9	15·8	12·2
19	Alberta domestic No. 5	6·9	7·6	7·2	8·8	16·6	11·6	4·1	7·2	5·9	1·4	2·4	1·9	10·4	17·6	13·6

Figure 5 is a graph showing the relation between the carbon dioxide content of the flue gas and the percentage of excess air. The effect of the dilution of the flue gases by the excess air is clearly shown, and the close

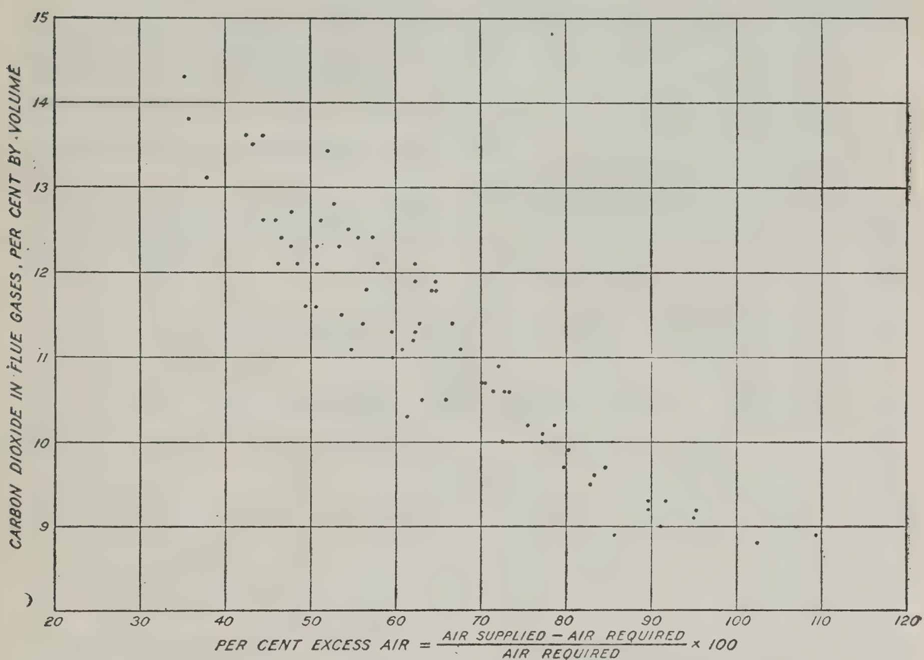

Figure 5.—Graph showing the relation between carbon dioxide content of the flue gas and per cent excess air.

proximity of all the points to a curve is, to a certain degree, a measure of the reliability of the flue gas analysis taken during this series of tests.

The five losses which were considered are:—

(1) Loss due to total heat of steam formed from moisture in fuel and that formed by combustion of hydrogen;

(2) Loss due to heat carried away in dry flue gases;

(3) Loss due to unburned combustible matter in refuse;

(4) Loss due to unburned carbon monoxide;

(5) Balance of heat account, due to errors of observation, radiation and unaccounted for loss.

These are all determined in the manner usual with steam boiler testing and probably no further discussion is needed here except for the last, i.e. *radiation and unaccounted for*, as the heat losses are gone into in the discussion which follows later covering each of the fuels tested.

RADIATION AND UNACCOUNTED FOR LOSS

The radiation and unaccounted for loss determined for the tests on all the fuels, except American anthracite, ranged from 10 to 27 per cent. That part of the loss due to radiation was estimated to be around 4 or 5 per cent. The remainder, the unknown part, was made up as follows:—

(1) Loss due to errors in judging the fuel bed, i.e. in not bringing the fuel bed at the end of the test to exactly the same condition as at the start;
(2) Loss due to unburned hydrocarbons in the flue gases, such as methane, ethylene, and hydrogen;
(3) Loss due to errors in measuring the temperature in the flue gases at the offtake of the furnace.

In order to determine, if possible, what loss might be expected from the first, a series of six short tests was made to compare the heat content of the fuel bed at the start of each of the tests, and the difference of this heat content between tests should give a measure of the loss due to errors in judging the fuel bed. The six tests were made on two fuels, viz., three on Alberta sub-bituminous coal No. 3 and three on American anthracite. Both furnaces were used and each test was conducted in the following manner:—

A fire was lit in each furnace at eight o'clock in the evening with the fuel under test. It was replenished once during the night, and at nine o'clock the following morning the fire was shaken down and brought to the condition that pertained at the start of the regular tests. The condition and depth of the fuel bed were carefully noted. The tests then proceeded as usual, with the exception that no further fuel was added and that readings of the temperatures and quantity of the cooling water were recorded every 15 minutes until the outlet temperature dropped to within 3 degrees of the inlet temperature, at which time for all practical purposes the fuel bed was burned out. Each test lasted in the neighbourhood of $7\frac{1}{2}$ hours. All the fuel bed was then shaken down into the ash-pit, the contents of which were carefully weighed, and after being quenched, were sent to the chemical laboratory to be analysed for the combustible matter content.

This procedure was followed with both fuels for the first test, and the procedure for the remaining two on each fuel was the same as that outlined above, with the exception that the test was started with the fuel bed in, as nearly as possible, the same condition as prevailed at the start of the first test.

In each test the heat delivered to the cooling water was calculated as usual, and it was estimated that the combustible matter in the refuse was pure carbon, having a calorific value of 14,500 B.T.U. per pound. From the combustible content given by the chemical analysis, the total heat in the refuse was determined. The total heat of the fuel bed at the beginning of the test was then the sum of the heat transferred to the cooling water and the heat content of the refuse, plus the following four heat losses: loss due to the sensible heat of the flue gases, loss due to the total heat of steam in the flue gases, loss due to unburned carbon monoxide, and loss due to radiation and unaccounted for. Probably the previous statement may be more clearly expressed in the form of the following equation:—

$$\left\{\begin{matrix}\text{Heat content of fuel}\\ \text{bed at start of test}\end{matrix}\right\} = \left\{\begin{matrix}\text{heat transferred}\\ \text{to cooling water}\end{matrix}\right\} + \left\{\begin{matrix}\text{heat content of the}\\ \text{refuse as dumped}\end{matrix}\right\} + \left\{\begin{matrix}\text{the four heat losses}\\ \text{mentioned.}\end{matrix}\right\}$$

Of the three parts constituting the right-hand side of the above equation, the first two are determined by the test, and a value is obtained for each

directly in B.T.U. in the manner before mentioned; the third will be assumed to be a constant for the three tests on Alberta sub-bituminous coal No. 3, and constant for the three tests on American anthracite.

From the above, the difference in original heat content of the fuel bed between any two tests of the three on each coal may be found; whence, knowing the calorific value of the fuel, the result can be converted into the equivalent of pounds of coal.

The results of these tests show that in judging the fuel bed, in no case was the difference in weight between any two tests on American anthracite greater than 7·1 pounds, and in the case of Alberta sub-bituminous coal No. 3, 15·3 pounds. This difference in estimating the fuel bed would account for an error of not more than seven-tenths of 1 per cent and 1·5 per cent respectively, provided 1,000 pounds of fuel were burned. The high unaccounted for loss in the majority of the tests must, therefore, be due to other causes.

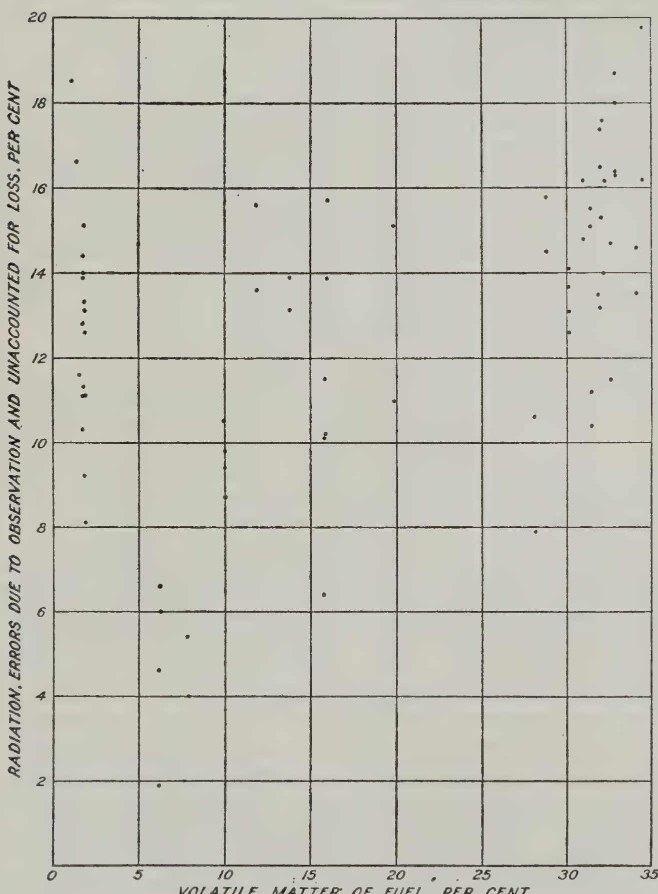

Figure 6.—Graph showing the relation between volatile matter of fuel and radiation, errors due to observation, and unaccounted for loss.

However, Figure 6 clearly indicates that the radiation and unaccounted for loss is greater for the high volatile fuels than for the cokes and anthracites. Although an attempt was made to analyse the flue gases for hydrogen, methane, and ethylene, no satisfactory results were obtained. It is the writers' opinion that possibly these high losses were due to faulty measurement of the temperature of the flue gases. The patented fixture at the offtake of the furnace might have caused eddy currents of cold air in the flue gases as they left the boiler, which would prevent the pyrometers from recording the true average temperatures of these gases.

DISCUSSION ON THE FUELS TESTED

AMERICAN ANTHRACITE

In all, fifteen tests were made on American anthracite coal. Unfortunately, the coal, as supplied in the different lots, varied considerably in ash content and calorific value. The ash content varied from 11·6 to 14·8 per cent of the fuel as fired and the calorific value from 11,990 to 12,760 B.T.U. per pound. Because of this wide diversity and in order to compare American anthracite with the other fuels, it was necessary to select one particular lot of the anthracite as being representative of this fuel; accordingly, the lot which had a calorific value of 12,090 B.T.U. per pound was selected. Four tests were made on this lot at three rates of combustion, viz.: Test G-58-A made at an approximate rate of 71,000 B.T.U. per hour; Tests G-59-A and G-59-B made at approximate rates of 101,000 and 99,000 B.T.U. per hour respectively, and Test G-58-B made at an approximate rate of 125,000 B.T.U. per hour. In the further discussion of American anthracite only the four above-mentioned tests are considered.

The *quantity of fuel fired per therm delivered* varied from 10·80 to 12·36 pounds, the average value being 11·39 pounds for the four tests considered. This average is higher than the corresponding averages for the other low volatile fuels such as the cokes and British anthracites, and is even slightly higher than for the semi-bituminous coals. Generalizing then, for American anthracite it may be said that the fuel consumption per unit of useful heat delivery was high in comparison with the fuels named above.

The necessary attendance required by furnace and fuel bed was a minimum in comparison with any of the other fuels that were tested. In the testing of this fuel 8-hour fire-periods were used for all rates of combustion and these fire-periods might easily have been extended to 12 hours, except possibly at the highest load. This characteristic of lengthy fire-period, along with uniform and adequate heat delivery, weighs very heavily with the average householder who attends to his own furnace, and is the main reason why American anthracite is regarded as such a desirable fuel.

The *total refuse removed* varied from 342 to 402 pounds per ton of fuel fired, the average value being 371 pounds. When expressed as a percentage this figure varied from 16·7 to 20·1 per cent of the fuel fired, with an average of 18·1 per cent. This is probably the worst feature of American anthracite, for when the percentage is 20, one-fifth of all the fuel fired to the furnace is removed again from the ash-pit. The clinker-forming

tendencies were found to be negligible in this series of tests, as only a very little clinker was formed at the highest load, and then it amounted to only 9·4 per cent of the total refuse removed.

The *thermal efficiencies* obtained in these tests may be considered high, and, certainly, the range in efficiency of from 66·9 to 76·6 per cent is wide for a fuel having such characteristic steadiness of burning and heat liberation, and especially so when the corresponding ranges for the other fuels that were tested are noted. At the lowest load the efficiency was 75·5 per cent, at the intermediate, viz., 101,000 and 99,000 B.T.U. per hour, the efficiencies were 72·3 and 76·6 per cent. The latter value seems so high that it might be questioned. At the highest load the efficiency dropped to 66·9 per cent. The average value for the four tests was 72·8 per cent.

The *heat losses* are, on the whole, very uniform when considered from item to item and from test to test, with the exception of Test G-59-B—the one showing the exceptionally high thermal efficiency. The *loss due to steam formed, etc.*, was very uniform, varying from 2·6 to 2·9 per cent. The same may be said of the *loss due to heat carried away in dry flue gases*—this loss varied from 6·3 to 12·9 per cent, the latter being the loss at the highest load when the furnace was forced. The *loss due to unburned combustible matter in refuse* is the greatest of all the losses, varying from 9·1 per cent at the lowest load, to 12·0 per cent for one of the tests on the intermediate load, viz., Test G-59-A. The *loss due to unburned carbon monoxide* was low, ranging from 0·4 to 0·5 per cent. The *balance of heat account due to errors of observation, radiation and unaccounted for loss* in comparison with the results of tests on other fuels was low, varying from 1·9 to 6·6 per cent, the former value being in the case of Test G-59-B. On account of this low loss, as well as the high thermal efficiency of 76·6 per cent, it is very questionable whether this test should be included in the series and used for discussion and charting. Tests G-59-A and G-59-B were run simultaneously, one in each furnace. The thermal efficiency in the one was 72·3 and in the other 76·6, while the unaccounted for loss was 4·6 in the first and 1·9 in the second.

The tests on American anthracite coal did not prove as satisfactory as the investigators had hoped, although the tests showed clearly the advantages, viz.: high thermal efficiency, small amount of attention required, and absence of clinker formation except at very high loads. The chief disadvantages are the large amount of refuse which had to be removed per ton of fuel fired and, to a lesser degree, the slightly larger amount of fuel fired per therm delivered, in comparison with the cokes, the British anthracites, and the semi-bituminous coals.

WELSH ANTHRACITE

Three 2-ton lots of Welsh anthracite coal were purchased from a local dealer, and six tests were made, of which one, namely Test G-19-A, is not considered in this discussion. The calorific value of the fuel used in the five tests here considered varied from 13,930 to 14,260 B.T.U. per pound, the average being 14,095. The results further show that for these five tests, the *quantity of fuel fired per therm delivered* varied from 9·35 to 9·78 pounds; the average value for the five tests was 9·56 pounds, being

the best obtained for any of the fuels during the entire investigation. The lowest value was obtained when the furnace was operated at a rate of 100,000 B.T.U. per hour, and the highest when the rate was 69,000 B.T.U. per hour.

The attendance required was very little, and although the fire-periods were 8 hours long a good fire could be maintained in the furnace at all rates of combustion for at least 12 hours.

The ash content of the three lots of fuel was exceptionally low and varied from 4·2 to 5·3 per cent. The combustible matter found in the refuse was high, the average value being approximately 45 per cent of the refuse, but very little refuse was removed from the ash-pit in any of the five tests. The quantity of refuse removed per ton of fuel fired was 115 pounds when the furnace was operated at its highest rate, viz., 135,000 B.T.U. per hour, and only 83 pounds when the furnace was operated at 100,000 B.T.U. per hour; the average value for the five tests being 94 pounds, or expressed in per cent the refuse removed was from 4·1 to 5·1 per cent of the total fuel fired, the average value being 4·8 per cent. When the furnace was being operated at moderate rates, viz., up to 102,000 B.T.U. per hour, no clinkers were formed, but above this rate a little clinker trouble was encountered. When the furnace was operated at a load of 135,000 B.T.U. per hour 11·3 per cent of the refuse formed was removed through the fire-door in the form of clinker.

The *thermal efficiency* ranged from 73·3 to 75·7 per cent, the average value for the five tests being 74·4 per cent. The highest efficiency was attained when the furnace was operated at an intermediate load and the lowest at the high load. These efficiencies compared very favourably with the other tests made on other fuels containing a low percentage of volatile matter such as the cokes and the anthracites.

Unfortunately, complete gas analyses were taken for only two of the tests, as in the earlier tests the investigators were very short-handed. The two tests where gas analyses were taken were G-35-A and G-35-B, the first when the furnace was operated at a rate of 102,000 B.T.U. per pound per hour, and the second at a rate of 100,000 B.T.U. per hour, both, therefore, being at intermediate loads. These two tests were made in separate furnaces at the same time, and, as might be expected, the results were very similar. The thermal efficiencies were 74·7 and 75·7, a difference of only 1 per cent. The *loss due to steam formed, etc.*, was low, being 2·6 per cent for the first test and 2·5 per cent for the other. The *loss due to heat carried away in dry flue gases* was 10·3 and 10·1 per cent respectively, and is the greatest single loss. The *loss due to unburned combustible matter in refuse* was 5·4 and 6·1 per cent respectively. These values are high, though not so high as those obtained when testing American anthracite. The *loss due to unburned carbon monoxide* was 1·6 per cent in each case, which is an average value for the low volatile fuels such as the cokes and anthracites. The *balance of heat account, etc.*, was 5·4 per cent for the first and 4·0 per cent for the second test. These are low values averaging less than for any of the other fuels tested.

The tests on Welsh anthracite coal fully substantiated all the claims that have been made for this fuel, viz., that it gives a high efficiency; very little refuse has to be removed; and that the fire requires very little

attention. If the furnace is given a reasonable amount of attention and the fire is not allowed to get low and is not forced, no trouble should be had from the formation of clinker. The fuel gives off heat at such a uniform rate that the user is likely to become careless and leave the furnace for too long a period without attention; then when the house becomes cold, the fire would be forced and clinker troubles would result.

SCOTCH SEMI-ANTHRACITE

Only four tests were made on this fuel which is commonly termed Scotch anthracite but as the fuel ratio of the coal was less than 10, being approximately 8 in value, it must properly be called a semi-anthracite. The calorific value of the fuel used in the four tests varied from 13,760 to 13,780 B.T.U. per pound, the average value being 13,770 B.T.U. per pound. The four tests were made at the following rates: 67,000, 101,000, 102,000, and 132,000 B.T.U. per hour. The *quantity of fuel fired per therm delivered* varied from 9·44 pounds at the lowest load to 10·24 pounds at the highest, the average value being 9·73 pounds for the four tests. These values are better than those obtained when testing American anthracite and approximate the values obtained for Welsh anthracite.

The *refuse removed from the ash-pit* averaged 135 pounds per ton of fuel fired and varied from 127 pounds at the highest load to 148 pounds for one of the intermediate loads, or, expressed in per cent, the total refuse varied from 6·4 to 7·4 per cent of the total fuel fired. The average figure is remarkably good when compared with American anthracite although it is a little higher than that obtained for Welsh anthracite. No clinkers were noticed except at the highest loads and then only 30·6 per cent of the total refuse removed was taken out through the fire-door in the form of clinker.

The length of fire-period adopted for all four tests was 8 hours, though at low loads the fire-period might have been extended to 12 hours. No attention was required between the times of firing—the draughts were set at the beginning of the tests and remained unaltered until the end.

The thermal efficiencies obtained were 76·8 per cent at low load, 75·9 and 75·1 per cent at intermediate loads, and 71·0 per cent at high load on the furnace, the average being 74·7 per cent. When comparing these efficiencies with those obtained when testing American and Welsh anthracites, the difference will immediately be noticed that for this fuel the highest efficiency was obtained when the furnace was operated at the lowest rate and not at the intermediate rate as for the other two fuels. This characteristic of the furnace, viz., that it operates at a higher efficiency at the lowest load, may be noticed for the majority of the tests on all fuels having a volatile matter content of 10 per cent or over. The average efficiency for all four tests was 74·7 per cent, the highest average obtained for the anthracites.

Flue gas analyses were obtained for each test and, therefore, a complete analysis of the losses was possible. The *loss due to steam formed, etc.*, was very uniform, varying from 2·7 to 3·0 per cent. The *loss due to heat carried away in dry flue gases* was not so uniform—it varied from 6·3 per cent at low load to 12·6 per cent at high load. This variation is a little greater than that obtained for the tests on Welsh anthracite, as might be expected, owing to the fact that the Scotch semi-anthracite has a higher

volatile matter content, and therefore it would be expected to burn with a longer flame and give, in consequence, a higher flue-gas temperature. The excess air was particularly uniform for this series of tests, averaging 51·8 per cent, whereas when Welsh anthracite was tested it averaged 71·7 per cent. The *loss due to unburned combustible matter in refuse* varied from 2·0 to 3·3 per cent, the average value being 2·7 per cent for all four tests. This loss is even lower than that obtained for Welsh anthracite. The *loss due to unburned carbon monoxide* was 1·4 per cent at the lowest load and 0·9 per cent for the remaining three tests. This loss also was low. The *balance of heat account, etc.*, averaged 9·6 per cent, being as low as 8·7 per cent at intermediate load and 10·5 per cent at high load. With the exception of the cokes it will be noted that throughout the investigation the general tendency was that the unacccounted for loss was higher for the fuels having the higher volatile matter content.

This group of tests proved to be the most uniform of any made during the whole investigation; the variations were less for all the items considered, and on the whole, the tests were very satisfactory, and they showed that this coal is almost an ideal fuel. The quantity of fuel fired per therm delivered was low; the thermal efficiencies, in consequence, were high; and the quantity of refuse removed per ton of fuel fired was exceptionally small. The only disadvantage that this fuel has is that it is more friable and a little more dusty than Welsh anthracite.

GAS COKE

The calorific value of this fuel varied from 11,955 to 12,250 B.T.U. per pound, the average value being 12,150 B.T.U. per pound. Eight tests in all were made on this fuel but only seven of them will be considered, as one of the tests was made when the investigators were comparatively inexperienced in the operation of the equipment and as no gas analyses were made on this test it was thought best to disregard it entirely. Of the seven tests considered three were made at the low rates of 68,000, 71,000, and 69,000 B.T.U. per hour; two at the intermediate rates of 101,000 and 99,000 B.T.U. per hour; and two at the high rate of 137,000 and 130,000 B.T.U. per hour.

The *quantity of fuel fired per therm delivered* varied from 10·82 to 11·76 pounds, the average being 11·21 pounds per therm. The lowest value was for one of the intermediate loads when the furnace was operated at a rate of 101,000 B.T.U. per hour. The figures are higher than those obtained for the Welsh and Scotch anthracites, but lower than the figure obtained for American anthracite.

When the length of fire-period is considered as a measure of the attendance required, the tests on gas coke showed that more attendance was required than for the tests on the anthracites, as the fire-periods were 8 hours for low loads and 6 hours for intermediate and high loads. However, when the householder has an oversize furnace, sufficient coke might be fired to lengthen out the fire-periods, but this cannot be done with all installations as gas coke is a much more bulky fuel than anthracite.

The *quantity of refuse removed per ton of fuel fired* varied from 240 pounds for one of the high load tests to 338 pounds for one of the low load tests, the average value for the seven tests being 277 pounds per ton. These

figures are higher than those obtained for the Welsh and Scotch anthracites, but are considerably less than for American anthracite. No clinker trouble was experienced except at high loads, and then the amount of clinker varied from 19·3 to 50·1 per cent of the total refuse removed. This is a wide variation but may be accounted for as these figures were obtained from tests on two different lots of fuel—one, no doubt, contained a more fusible ash than the other.

The *thermal efficiencies* varied from 69·5 to 75·4 per cent, the average value being 74·9 per cent; the highest efficiencies were obtained for the intermediate loads and the lowest for the highest loads. The coke contained little moisture, and therefore the *loss due to steam formed, etc.*, was low, varying only from 0·5 to 0·6 per cent. The *loss due to heat carried away in dry flue gases* at low loads varied from 6·3 to 7·4 per cent, and at intermediate loads from 11·0 to 11·3 per cent. Flue gas analyses were obtained for only one of the tests at high load, when the loss was 15·6 per cent. The excess air was fairly uniform, varying from 35·7 to 64·4 per cent, the highest excess air being noted for the tests at the higher loads. The *loss due to unburned combustible matter in refuse* was low throughout the tests, varying from 0·8 to 3·8 per cent. This loss was as low as that obtained when testing Scotch anthracite, a little less than that obtained when burning Welsh anthracite, and considerably less than that obtained when burning American anthracite. The *loss due to unburned carbon monoxide* was slightly higher than that found when testing the anthracites; it varied from 1·1 to 3·6 per cent. The value of 3·6 per cent for Test G-29-A was the greatest obtained for any of the tests conducted in the investigation. The *balance of heat account, etc.*, was comparatively high, varying from 8·1 to 13·3 per cent.

On the whole the gas coke compared favourably with the anthracites. The *quantity of fuel fired per therm delivered* was a little greater than for the Welsh and Scotch anthracites, but slightly less than for American anthracite, and the efficiencies were higher than those obtained with American anthracite, and in comparison was distinctly better than the latter in respect to refuse removed per ton of fuel fired. The bulkiness of gas coke, which necessitates shorter fire-periods, is its only disadvantage in comparing it with the anthracites.

BY-PRODUCT COKE NO. 1

As only 3 tons of this fuel were available for testing purposes only two tests were made, one at a rate of 67,000 and the other at a rate of 132,000 B.T.U. per hour. The ash content of the fuel was approximately 13 per cent and its calorific value 11,930 B.T.U. per pound.

At the time the tests were made it was not feasible to take flue gas analyses and therefore no analysis of the heat balance can be made. Other results obtained are given in Table VI, and show that this coke was of an exceptionally poor quality; and because of the unreliability of the results the two tests were disregarded.

BY-PRODUCT COKE NO. 2

The calorific value of this fuel varied with the moisture content, from 12,940 to 13,040 B.T.U. per pound, and averaged 12,990 B.T.U. Although six tests were made on this fuel, only four were accepted for con-

sideration, namely, one made at the low rate of 68,000 B.T.U. per hour, two made at the intermediate rates of 100,000 and 101,000 B.T.U. per hour, and one made at the high rate of 135,000 B.T.U. per hour. The *quantity of fuel fired per therm delivered* varied from 10·18 pounds when the rate was 68,000 B.T.U. per hour, to 10·57 pounds when the rate was 135,000 B.T.U. per hour. The average value for the four tests was 10·33 pounds per therm, being slightly lower than the average for gas coke and is considerably lower than the average for American anthracite.

Eight-hour fire-periods were employed with the exception that at the high load the period was reduced to six hours. Little attention was required when burning this fuel. It ignited readily and burned at a very uniform rate.

The *quantity of refuse removed per ton of fuel fired* varied from 125 to 154 pounds averaging 142 pounds for the four tests. This is a very low figure and is excelled only by the Welsh and Scotch anthracites. No difficulty was experienced by formation of clinker and only at high load was it noticeable when 14·8 per cent of the refuse was removed through the fire-door in this form. The *total refuse removed* expressed as a percentage of the fuel fired varied from 6·2 to 10·4 per cent. This small amount of refuse makes this coke a most attractive fuel for the householder.

The *thermal efficiencies* for the tests varied from 72·5 to 75·5 per cent, and for the four tests the average was 74·5 per cent. These figures were high and remarkably uniform for the four tests. The *loss due to steam formed, etc.*, was low, and varied from 0·6 to 0·7 per cent. The *loss due to heat carried away in dry flue gases* amounted to 6·4 per cent at low load and varied for the remainder of the tests up to a maximum of 11·7 per cent at high load. The *loss due to unburned combustible matter in refuse* varied from 0·8 per cent for high load to 1·4 per cent for the test at low load. The *loss due to unburned carbon monoxide* was 1·5 per cent at high load, and varied up to 2·4 per cent for the test at low load. The *balance of heat account, etc.*, varied from 10·3 per cent for one of the tests at intermediate load to 13·9 per cent for Test G-44-A, which was made at low load. These figures show that this loss was very uniform, being higher than that for the anthracites but almost the same as those obtained when testing gas coke.

The four tests gave very uniform results. The values obtained for the *quantity of fuel fired per therm delivered* were very satisfactory. These figures, with those showing the quantity of refuse removed per ton of fuel fired, were considerably lower than for the same values obtained for gas coke. The high thermal efficiency, low quantity of fuel fired per therm, and small amount of refuse to be removed, make this fuel a very desirable one for the average householder, and more especially so for the one who is fortunate enough to have an oversize furnace.

BY-PRODUCT COKES NOS. 3 AND 4

Two lots of this coke were purchased; one 4-ton lot of small size coke which was termed by-product coke No. 3, and a second lot of 1¼ tons of medium size coke which was termed by-product coke No. 4.

Four accepted tests were made on the small size coke; one at a rate of 67,000 B.T.U. per hour, two at rates of 103,000 and 99,000 B.T.U. per

hour, and one at a rate of 136,000 B.T.U. per hour. The calorific value varied from 12,900 to 13,100 B.T.U. per pound, the average value being 13,020 B.T.U. per pound, the variations in calorific value were due in all probability to difference in moisture content and to errors in sampling. The *quantity of fuel fired per therm delivered* varied from 10·50 to 11·16 pounds, averaging for the four tests 10·85 pounds per therm. The *quantity of refuse removed* per ton of fuel fired was 132 pounds at low load, 167 and 207 pounds at intermediate loads, and 153 pounds at high load, the average value being 165 pounds, showing comparatively small variation. When the refuse removed was expressed as a percentage of the total fuel fired, it was 6·6 per cent for low load, 8·4 and 10·3 per cent for intermediate loads, and 7·6 per cent for high load. Clinkers were formed during each of the tests with the exception of the one at low load. At the intermediate loads, 38·3 and 28·4 per cent of the total refuse was removed through the fire-door in the form of clinker, and at high load, 54·5 per cent.

The *thermal efficiencies* were 73·6 per cent at low load, 69·9 and 68·4 per cent at intermediate loads, and 71·6 per cent at high load. These figures show rather wide variation and are not very satisfactory, being higher at both high and low loads than at intermediate loads. The *loss due to steam formed, etc.*, was uniform throughout, being 0·5 per cent for all tests except that at high load when it was 0·6 per cent. Wide variation was noted in the *loss due to the heat carried away in the dry flue gases*, viz., 7·5 per cent; this loss varied from 5·5 per cent at low load to 13·0 per cent at high load. However, if the test at low load were disregarded the other three tests would show a variation of only 2·8 per cent, which would be very satisfactory. The *loss due to unburned combustible matter in refuse* varied from 1·3 to 4·1 per cent and was 2·7 per cent at low load, 2·9 and 4·1 at intermediate loads, and 1·3 per cent at high load, and on the whole, may be considered very low. The *loss due to unburned carbon monoxide* was 1·1 per cent at low load, 2·5 and 2·1 per cent at intermediate loads, and 1·9 per cent at high load; these are fairly low results. The *balance of heat account, etc.*, varied slightly, the minimum and maximum values being 11·6 per cent at high load and 16·6 per cent at low load.

BY-PRODUCT COKE NO. 4

Three tests were conducted on the medium size coke; one at 69,000, one at 105,000, and one at 136,000 B.T.U. per hour, i.e. low, medium, and high loads. The calorific value of the fuel varied from 12,960 to 13,120 and the average value was 13,010 B.T.U. per pound. The *quantity of fuel fired per therm delivered* varied from 10·23 pounds at intermediate load to 11·38 pounds at high load, the average was 10·81 pounds per therm. The *quantity of refuse removed* per ton of fuel fired varied from 118 pounds at intermediate load to 179 pounds at low load—a fairly wide variation, although at low and at high loads they were practically the same, viz., 179 to 170 pounds per ton. No clinker was formed except at high load and then only 15·3 per cent of the total refuse removed was in this form. The *total refuse removed,* expressed as a percentage of the total fuel fired, varied from 5·9 to 9·0 per cent.

The *thermal efficiencies* were 71·2 per cent at low load; 75·4 per cent at intermediate load, the highest recorded for this fuel; and 67·0 per cent at high load, the lowest for this fuel; averaging for the three tests 71·2 per cent, which is slightly higher than that obtained when testing the smaller size. The *loss due to steam formed, etc.*, was identical with the same loss found when testing the smaller size. The *loss due to heat carried away in the dry flue gases* varied from 5·9 per cent at low load up to 9·8 per cent at high load, the average value being 7·6 per cent, whereas the average for the small size coke was 9·8 per cent. The *loss due to unburned combustible matter in refuse* was slightly higher for this size fuel than for the smaller size of the same fuel; it varied from 2·9 per cent at intermediate load to 5·1 per cent at low load. The high value for this loss at low load is due, no doubt, to more vigorous shaking of the grate during this particular test. The *loss due to unburned carbon monoxide* varied from 1·0 per cent at high load to 2·8 per cent at intermediate load; the average for this series was only one-tenth of 1 per cent higher than when testing the small size. The *balance of heat account, etc.*, was fairly uniform, although the variation was greater for this series than when testing the smaller size.

When the two groups of tests on by-product cokes Nos. 3 and 4 are compared one with the other, the results show that the medium size coke is better suited for the type of furnace employed during this investigation than is the small size. This is particularly noticeable with respect to the amount of clinker formed. No clinker was formed when testing medium size coke at intermediate load, whereas when testing the small size at this load, 38·3 and 28·4 per cent of the total refuse removed was in the form of clinker. And, further, when testing at high load only 15·3 per cent of the total refuse removed was in this form when the medium size coke was tested, and when testing the small size at the same load it was 54·5 per cent.

The results obtained from tests on this fuel showed that it was admirably suited for domestic furnaces such as the one employed during the investigation. The quantity of fuel fired per therm delivered, although slightly higher than the values obtained when testing by-product coke No. 2, was very satisfactory, being less than for gas coke and considerably less than for American anthracite. The quantity of refuse removed per ton of fuel fired was low and bears the same relation to the other fuels, as did the quantity of fuel fired per therm delivered. The thermal efficiencies were not quite so high as when testing by-product coke No. 2, but this characteristic is of little consequence when the quantity of fuel fired per therm delivered is low. The attendance required was a little greater than when testing the anthracite fuels. It was found necessary to reduce the fire-periods at high load from 8 to 6 hours, but no difficulty was encountered when using an 8-hour fire-period at intermediate load. The attendance required was about the same as when testing by-product coke No. 2 and considerably less than when testing gas coke, although more trouble arose due to the formation of clinker.

AMERICAN SMOKELESS SEMI-BITUMINOUS COAL NO. 1

Nine tests were conducted on this fuel; three at low load, five at intermediate load, and one at high load. Four were of long duration, varying from 78 hours at high load to 120 hours at low load. The other

five were of short duration, viz., 24 to 32 hours, and on that account were disregarded. The calorific value of this fuel varied from 13,930 to 14,060 B.T.U. per pound, the variation being due to the evaporation of moisture while it was in storage and to errors in sampling.

The *quantity of fuel fired per therm delivered*, which varied from 10·72 to 11·30 pounds with an average of 10·93 pounds for the four accepted tests, was very uniform, being approximately the same for each load. The *quantity of refuse removed per ton of fuel fired*, varied from 147 to 166 pounds per ton, the average being 155 pounds. A moderate amount of clinker was removed through the fire-door during the tests. At high load the clinker was 27·7 per cent of the total refuse removed—the maximum figure for this item—and at low load it was 9·2 per cent, being the minimum. In none of the four accepted tests was the refuse more than 9 per cent of the total fuel fired.

Considerably more attention was required when burning this fuel than when burning the cokes and the anthracites, although the fire-period was 8 hours throughout, with the exception of the test at high load when it was reduced to 6 hours. This coal coked and after firing, when all the volatile matter had been driven off, it was necessary to break up the coke with a poker and spread it over the fuel bed. Two methods of firing were adopted; the first method was to fire the coal on only one side of the fire-pot, leaving a part of the glowing fuel bed exposed in order that the volatile gases given off by the freshly charged fuel might be readily ignited and burned; the second method was to fire the freshly charged fuel around the perimeter of the fuel bed, leaving a bright spot in the centre to ignite the gases. After a number of tests had been made using each method, the first was finally found to be more satisfactory and was adopted for the remainder of the tests on the semi-bituminous and Alberta fuels. Owing to the fact that the fuel burned through where the bright spots had been left, and permitted the free passage of air from the ash-pit through the combustion zone to the flue, the quantity of excess air was high, averaging 88·9 per cent.

The *thermal efficiencies* for the four tests averaged 65·4 per cent, varying from 63·0 per cent for the test at high load to 67·0 per cent for one of the tests at intermediate load. These figures were lower than those for the cokes and the anthracites, and were very uniform, none varying more than 2·4 per cent above or below the average. The *loss due to steam formed, etc.*, was higher than when the anthracites and cokes were tested, varying from 3·4 to 3·7 per cent. These high figures were due, no doubt, to the higher hydrogen content of the fuel as the moisture content was low. The *loss due to heat carried away in dry flue gases* varied from 11·3 per cent for the test at low load to 19·4 per cent for the test at high load. This latter figure is extremely high and it might be attributed to a possible error in the temperature of the flue gases, as *the unaccounted for loss* for this test was only 11 per cent, being the lowest value obtained for this fuel. The *loss due to unburned combustible matter in refuse* averaged 2·1 per cent, varying from 1·5 per cent for one of the tests at intermediate load, to 3·1 per cent for the test at low load. These values are quite uniform and lower than the average for the investigation. The *loss due to unburned carbon monoxide* was low, amounting to an average of 1·4 per cent, varying

from 1·2 up to 1·7 per cent. These low values may be accounted for by the large amount of excess air diluting the flue gases. The *balance of heat account, etc.*, varied from 11·0 up to 15·6 per cent, giving an average value of 13·3 per cent.

Smokeless semi-bituminous coal, if as characterized by this fuel, is a very satisfactory fuel when burned in the type of domestic furnace employed during the investigation. It has a high calorific value and low ash content. The quantity of fuel fired per therm delivered was lower than that for American anthracite and gas coke, although not so low as that for the other anthracites and cokes. The quantity of refuse removed was much lower than for American anthracite and gas coke, though higher than for the Welsh and Scotch anthracites and the by-product cokes. The only disadvantage that this fuel has is that it requires more attention; not that the fuel has to be fired any oftener but that an hour or so after fresh coal has been charged it is necessary to break up the coke and coal with a poker and spread it over the fuel bed; also, greater care must be taken with the alternate firing of the coal to ensure that a bright spot be left showing in the fuel bed to ignite the gases as they are given off from the freshly charged fuel.

AMERICAN SMOKELESS SEMI-BITUMINOUS COAL NO. 2

Four tests were conducted on this fuel, viz., one at low load, 68,000 B.T.U. per hour; two at intermediate load, 96,000 and 97,000 B.T.U. per hour; and one at high load, 122,000 B.T.U. per hour. The calorific value for two of the tests was 14,020, and the calorific value for the other two was 13,750, the variation being due to errors in sampling; the average value was 13,890 B.T.U. per pound for the four tests. These values are slightly lower than the calorific values of semi-bituminous coal No. 1.

The *quantity of fuel per therm delivered* varied from 10·55 pounds at low load to 11·25 pounds at high load and the average was 11·01 pounds per therm. These values were slightly lower than for semi-bituminous coal No. 1, and considerably lower than for American anthracite, but higher than for the cokes and other anthracites. The *quantity of refuse removed* per ton of fuel fired averaged 231 pounds for the four tests, varying from 196 pounds at high load to 254 pounds at low load. This average figure is higher than the average for semi-bituminous coal No. 1 and the cokes and anthracites, with the exception of gas coke and American anthracite, which, in both cases, were higher. At high load, 33·6 per cent of the refuse removed was in the form of clinker; at low load only 4·2 per cent was clinker; for one test at intermediate load no clinker was formed and for the other test 7·0 per cent of the refuse was in the form of clinker. These figures are slightly higher than for semi-bituminous coal No. 1. The quantity of refuse removed, expressed as a percentage of the fuel fired, varied from 9·8 per cent at high load to 12·7 per cent at low load. These figures are less than for American anthracite and gas coke, but greater than for semi-bituminous coal No. 1 and the other cokes and anthracites.

Eight-hour fire-periods were employed for low load and intermediate load but at high load the period was reduced to six hours. The attendance required was the same as when testing semi-bituminous coal No. 1, i.e.

the coal had to be fired very carefully so as to leave part of the glowing fuel bed exposed after charging the raw fuel, in order that the volatile gases would be immediately ignited when given off. An hour or two after fresh coal had been fired, it was necessary to break up the coke which had formed after the volatile gases had been driven off. No further attention was required beyond the necessary altering of the draughts to regulate the rate of burning. The regulation of draughts is common to all fuels whether being tested in a laboratory installation or being burned in a household furnace.

The *thermal efficiencies* obtained varied from 63·4 per cent at high load to 67·5 per cent at low load, the average figure for the four tests was 65·4 per cent. This figure is higher than that obtained when testing semi-bituminous coal No. 1 but lower than the average efficiency for the cokes and the anthracites. The *loss due to steam formed, etc.*, varied from 3·3 per cent at low load to 3·6 per cent at high load. These high figures are due to the high hydrogen content of the fuel and varied slightly with the temperature of the flue gases. The *loss due to heat carried away in dry flue gases* was very uniform, being 11·3 per cent at low load and 15·8 per cent at high load, giving an average for the four tests of 14·0 per cent. The variation agrees with the rise in flue gas temperature as the load on the furnace was increased with the exception of one test, viz., G-60-A, where this loss was 15·0 per cent. However, this can be accounted for by the fact that the excess air was very high, viz., 109·4 per cent. The *loss due to unburned combustible matter in refuse* compared very favourably with the figures obtained for the cokes and the anthracites, and was slightly lower than that obtained for semi-bituminous coal No. 1. The *loss due to the unburned carbon monoxide* amounted to less than 1 per cent for all tests, averaging 0·6 per cent. The *balance of heat account, etc.*, averaged 13·8 per cent. The minimum and maximum figures for this fuel were 11·9 per cent for one of the tests at intermediate load and 15·7 per cent for high load.

The results obtained with this fuel compare very favourably with the results obtained when testing semi-bituminous coal No. 1, and as a substitute fuel it is very desirable for the average householder if he has a standard type of hot-water furnace. More attendance is required than when burning the cokes or the anthracites, but the quantity of fuel fired per therm delivered was lower for this fuel than for American anthracite, although slightly higher than for some of the cokes. No undue trouble would arise owing to the formation of clinkers if care were taken not to force the rate of combustion in the furnace. Care must be taken in firing this fuel in order that a bright spot be left showing in the fuel bed to ignite the volatile gases as they are given off, and the fuel, after coking, must be broken up and spread across the fuel bed, otherwise a hole will be burned in the fuel bed which will allow an excess of air to pass through, thereby cooling the heating surface, which would eventually lower the temperature of the water in the radiators.

ALBERTA SEMI-BITUMINOUS COAL

Nine tests in all were conducted on this coal but five of these were disregarded for various reasons. The average calorific value for this fuel for the four tests considered was 13,320 B.T.U. per pound; 13,340 and

13,300 B.T.U. per pound were the maximum and minimum values. This fuel had the highest calorific value of any of the coals received from the province of Alberta and was higher in this respect than American anthracite and the different cokes tested, but was lower in this respect than were the other two anthracites and the two semi-bituminous coals. This fuel is very low in moisture, averaging less than 1 per cent, but is rather high in ash, averaging 13·2 per cent.

The *quantity of fuel fired per therm delivered* averaged 11·28 pounds and ranged from 11·18 to 11·39 pounds per therm, the low figure being for Test G-55-A when the furnace was operated at the low rate of 69,000 B.T.U. per hour, and the high figure, viz. 11·39, for Test G-55-B when the furnace was operated at a rate of 133,000 B.T.U. per hour. The average figure, 11·28 pounds per therm, stood midway in value between the other two semi-bituminous coals, the values for which were both higher than for the cokes and the anthracites, with the exception of American anthracite and gas coke. Eight-hour fire-periods were employed for the tests at low and intermediate loads, but at high load it was found necessary to operate on a 6-hour fire-period. Great care had to be taken in charging the raw fuel onto one side of the grate only, so as to leave a bright spot by which the fresh gases given off would be ignited. This fuel caked slightly and it was found advantageous to break up the fuel after it had caked across the fuel bed.

The *thermal efficiencies* for the four tests considered averaged 66·6 per cent, ranging from 66·0 per cent at high load to 67·2 per cent at low load. These figures are higher than those obtained when testing the other semi-bituminous coals. The *loss due to steam formed, etc.*, varied from 3·2 to 3·6 per cent. This loss is practically the same as for the other two semi-bituminous coals. The *loss due to heat carried away in the dry flue gases* averaged 13·2 per cent and varied from 8·4 per cent at low load to 16·5 per cent at high load. The average figure compares very favourably with the averages obtained for the other semi-bituminous coals. The *loss due to unburned combustible matter in refuse* was 14·2 per cent at low load, 6·4 and 3·7 per cent at intermediate load, and 3·8 per cent at high load, averaging 7·0 per cent. This figure is higher than for any of the other fuels with the exception of American anthracite, and is due to the fine coal sifting through the fuel bed into the ash-pit. The *loss due to unburned carbon monoxide* was very low, amounting to 0·6 per cent at low load, 0·5 per cent for one of the tests at intermediate load, and nil for the other two tests. The *balance of heat account, etc.*, averaged 9·5 per cent, ranging 6·4 per cent at low load to 11·5 per cent for one of the tests at intermediate load, and is slightly lower than this loss for the other two semi-bituminous coals. This loss was considerably lower than for the cokes and the anthracites, with the exception of American anthracite for which this loss was very low indeed.

The *quantity of refuse removed per ton of fuel fired* averaged 293 pounds and varied from 252 pounds for one of the tests at intermediate load to 363 pounds for the test at low load. When expressed as a percentage of the total fuel fired, the amount of refuse removed averages 13·3 per cent. This figure is larger, owing to the higher ash content of this fuel, than for the other two semi-bituminous coals and is about the same as the average

value for gas coke, but is higher than for the other cokes and anthracites. Considerable difficulty was encountered from the formation of clinkers at intermediate and high loads, but little at low load.

This fuel disintegrated a great deal on storage, and great care had to be taken in poking the fuel bed in order that the very fine fuel would not sift through into the ash-pit and thereby be wasted. The results obtained from the four tests considered show that this fuel may be burned to advantage in this type of furnace. The quantity of fuel fired per therm delivered was low and the overall thermal efficiencies obtained were high.

ALBERTA SUB-BITUMINOUS COAL NO. 1

Six tests were conducted on this fuel but only four are considered here. The other two were tests of short duration, and gave unsatisfactory results on that account. This coal is classed as sub-bituminous by the Scientific and Industrial Research Council of the province of Alberta and had an average calorific value of 11,180 B.T.U. per pound, the range being from 11,110 to 11,240 B.T.U. per pound. It was found necessary to use the following lengths of fire-period: at low load, 8 hours; at intermediate load, 6 hours; and at full load, 4 hours. These fire-periods could, no doubt, have been considerably lengthened but in doing so large fluctuations would have occurred in the load curves. With the length of fire-period used, the attendance required was more than with the cokes and the anthracites.

The quantity of fuel fired per therm delivered averaged 14·77 pounds and ranged from 13·89 pounds at low load, to 15·27 pounds at intermediate load. These figures are considerably higher than those obtained when testing Alberta semi-bituminous coal. The *quantity of refuse removed per ton of fuel fired* varied from 174 pounds at high load to 225 pounds at low load, and the average value was 194 pounds per ton. If expressed as a percentage of the total fuel fired, the average would be 9·8 per cent. Clinkers were formed during all tests but gave no great trouble. On an average, 34·5 per cent of the total refuse was removed in the form of clinker through the fire-door.

The *thermal efficiency* of the furnace when operated at low load was 64·1 per cent, at intermediate load 58·9 and 60·4 per cent, and at high load 59·3 per cent. The average for the four tests was 60·7 per cent. It will be noted that the efficiency was greatest when the furnace was being operated at low load. This is a marked characteristic of all the Alberta fuels. The *loss due to steam formed, etc.*, averaged 5·2 per cent. The *loss due to heat carried away in the dry flue gases* averaged 14·9 per cent, which is considerably higher than that obtained when testing American anthracite. The *loss due to unburned combustile matter in refuse* averaged 3·7 per cent, varying from 2·2 per cent for one of the tests at intermediate load, to 5·9 per cent for the test at low load. This figure is fairly low due to the fact that the fuel was in large pieces and did not sift through into the ash-pit when the fuel bed was poked or the grates shaken. The *loss due to unburned carbon monoxide* varied from 0·5 per cent at low load and high load, to 2·4 and 2·2 per cent at intermediate load, the average value was 1·4 per cent. This figure is fairly low, although higher than that obtained

when testing the semi-bituminous coals. The *balance of heat account, etc.*, averaged 14·1 per cent, ranging in value from 11·5 per cent at high load, to 16·2 per cent for one of the tests at intermediate load.

The disadvantages of this fuel are that it cannot be burned with high efficiency in this type of furnace. Therefore, the quantity of fuel fired per therm delivered must necessarily be greater than that obtained when testing American anthracite. When an even heat is required in the house it would be necessary to fire this fuel every six hours, except when operating the furnace at a very low rate as would be the case if an oversize furnace were installed. To offset these disadvantages the fuel is very clean to handle and does not break readily upon storage. Only 9·8 per cent of the total fuel fired is removed as refuse, as compared with nearly 20 per cent in the case of American anthracite. This is a very desirable feature for the householder. No undue clinkering troubles were encountered.

ALBERTA SUB-BITUMINOUS COAL NO. 2

This fuel was classed as a sub-bituminous coal by the Scientific and Industrial Research Council of the province of Alberta. Nine tests in all were conducted on this fuel, only four of which are included in this discussion. The other five were disregarded for various reasons, but principally because they were all of short duration. The calorific value averaged 10,800 B.T.U. per pound and was 10,740 for the tests at low and high load and 10,860 for the tests at intermediate load. The fire-periods employed were 8 hours at low load, 6 hours at intermediate load, and 4 hours at high load. When employing these fire-periods a very uniform curve of heat output was obtained, the variations being slight between maximum and minimum.

The *quantities of fuel fired per therm delivered* were as follows: 15·04 pounds at low load, 15·18 and 15·82 pounds at intermediate load, and 16·16 pounds at high load, giving an average value of 15·55 pounds per therm. This figure is higher than that obtained when testing sub-bituminous coal No. 1, due almost entirely to its having a lower calorific value, although the efficiency was slightly lower as well. The *quantity of refuse removed per ton of fuel fired* varied from 223 pounds for one of the tests at intermediate load to 286 pounds for the test at low load; the average for the four tests was 258 pounds per ton. The percentage of refuse removed through the fire-door in the form of clinker averaged 36·1 per cent. These tests show that this coal clinkered just a little more than did sub-bituminous coal No. 1.

The *thermal efficiencies obtained* were 61·9 per cent at low load, 60·6 and 58·2 per cent at intermediate load, and 57·6 per cent at high load, showing that the coal burns in this type of furnace with the highest efficiency at low load. The average thermal efficiency was 59·6 per cent, which value is a little lower than the average figure obtained when testing sub-bituminous coal No. 1. The average for the *loss due to steam formed, etc.*, was 5·3 per cent. This loss varied from 5·1 per cent at low load to 5·6 per cent at high load. The *loss due to heat carried away in the dry flue gases* varied from 10·2 per cent at low load to 16·4 per cent at high load, which gave an average of 13·5 per cent for all four tests. The *loss due to unburned*

combustible matter in refuse averaged 4·9 per cent, a slightly higher figure than the corresponding figure for sub-bituminous coal No. 1, due to the fact that when testing sub-bituminous coal No. 2 considerably more refuse was removed, and therefore, as might be expected, it had associated with it more combustible matter than for sub-bituminous coal No. 1. The *loss due to unburned carbon monoxide*, however, was just half the average figure for sub-bituminous coal No. 1, being 0·7 per cent in the first case and 1·4 per cent in the latter. The *balance of heat account, etc.*, varied from 13·5 per cent at high load to 19·8 per cent for one of the tests at intermediate load, the average for the four tests being 16·0 per cent, or practically 2 per cent higher than when testing sub-bituminous coal No. 1.

This fuel has excellent burning qualities. The rate of combustion can be very rapidly increased. Clinkering gave very little trouble, and the *quantity of refuse removed per ton of fuel fired* was low in comparison with American anthracite, being only 12·9 per cent for this fuel.

ALBERTA SUB-BITUMINOUS COAL NO. 3

This coal is classed as sub-bituminous by the Scientific and Industrial Research Council of the province of Alberta. Six tests were conducted on this fuel, four of which are included in the following discussion. Fire-periods of 8 hours were adopted for tests at low load, 6 hours for tests at intermediate load, and 4 hours for tests at high load. The calorific value of this fuel averaged 10,830 B.T.U. per pound on the "as fired" basis, the range in calorific value being from 10,820 to 10,840 B.T.U. per pound. These values are slightly higher than for sub-bituminous coal No. 2.

The *quantity of fuel fired per therm delivered* ranged from 14·46 pounds for the test at low load to 16·98 pounds for the test at high load and the average value for the four tests was 15·95 pounds per therm. This latter figure is higher than the same item for both of the other sub-bituminous coals. The average figure for the *quantity of refuse removed per ton of fuel fired* was 225 pounds and was very uniform for all four tests, varying from 218 to 229 pounds. A considerable quantity of clinker was formed at all loads. The average figure for the clinker produced when expressed as a percentage of the total refuse removed was 57·0. This figure is higher than that for either of the other two sub-bituminous coals.

The average thermal efficiency for the four tests was 58·1 per cent and varied from 54·4 per cent at high load to 63·9 per cent for one of the tests at low load. The *loss due to steam formed, etc.*, varied from 5·5 to 6·1 per cent with an average value of 5·8 per cent, and is slightly higher than for sub-bituminous coal No. 2. The *loss due to heat carried away in the dry flue gases* varied from 8·3 per cent for one of the tests at low load to 18·7 per cent for the test at high load. The *loss due to unburned combustible matter in refuse* was low averaging 3·0 per cent. The *loss due to unburned carbon monoxide* varied from 0·9 to 2·3 per cent and averaged 1·8 per cent. The *balance of heat account, etc.*, was fairly high, averaging 17·4 per cent, and varied from 16·3 per cent at high load to 18·7 per cent at one of the intermediate loads.

No trouble was encountered when burning this fuel and the observers noted that it was very easily handled. Although clinkers were formed they were not at all troublesome, being easily broken up and removed.

ALBERTA DOMESTIC COAL NO. 1

This fuel was classed by the Scientific and Industrial Research Council of the province of Alberta as Alberta domestic. Four tests were made on the fuel: one at high load, two at intermediate load, and one at low load. The calorific value averaged 9,410 B.T.U. per pound for the four tests. The fire-periods were 8 hours for low load, 6 hours for intermediate load, and 4 hours for high load.

The *quantity of fuel fired per therm delivered* was 16·03 pounds at low load, 17·30 and 16·98 pounds at intermediate load, and 18·25 pounds at high load, averaging 17·14 pounds per therm. This figure shows that domestic coal No. 1 when burned in this type of furnace is not so economical to use as the sub-bituminous coals when the comparison is made on the pound for pound basis. The *quantity of refuse removed per ton of fuel fired* averaged 177 pounds and varied from 158 pounds for one of the tests at intermediate load to 184 pounds for the test at high load. These figures are very low and are lower than for any of the other Alberta fuels with the exception of domestic coal No. 3. The average figure for the refuse removed when expressed as a percentage of the total fuel fired, is 8·8. Clinkers were formed during each test and on the average, 47·7 per cent of the total refuse removed was in the form of clinker. This clinker, however, was not troublesome and was very easily broken up and removed through the fire-door.

The *thermal efficiencies* obtained during the four tests were as follows: 66·3 per cent at low load, 61·4 and 62·5 per cent at intermediate load, and 58·4 per cent at high load, giving an average value for all four tests of 62·2 per cent. These figures, although not so high as the figures obtained when testing domestic coal No. 4, are higher than for the other Alberta domestic fuels. The *loss due to steam formed, etc.*, averaged 6·9 per cent, a considerably higher figure than that obtained when testing the sub-bituminous fuels, but not quite so high as when testing domestic coal No. 5. The *loss due to heat carried away in the dry flue gases* varied from 9·2 per cent at low load to 16·4 per cent at high load and averaged 12·3 per cent. This latter figure is about an average figure when all the Alberta fuels are considered. The *loss due to unburned combustible matter in refuse* averaged 4·3 per cent and showed very little variation from low load to high load, and was a very average loss for the Alberta coals. The *loss due to unburned carbon monoxide* varied from 0·5 per cent at low load to 1·3 per cent for one of the tests at intermediate load, and averaged approximately 1 per cent. This loss is comparatively low. The *balance of heat account, etc.*, averaged 13·4 per cent and ranged from 12·6 per cent at low load to 14·1 per cent for the tests at intermediate load.

This fuel was very clean to handle, being bright and shiny and did not disintegrate to any extent. The average thermal efficiency when testing this fuel was high, although not quite so high as that obtained when testing domestic coal No. 4. For this reason the quantity of fuel fired per therm delivered was fairly low in comparison with the calorific value of the fuel. The quantity of refuse removed per ton of fuel fired

was exceedingly low which makes it an admirable fuel for domestic purposes. A fairly large amount of clinker was formed during each test but it did not prove unduly troublesome.

ALBERTA DOMESTIC COAL NO. 2

This fuel is classed by the Scientific and Industrial Research Council of the province of Alberta as Alberta domestic. Six tests in all were conducted on this fuel, only four of which are considered in this discussion. The other two tests were of short duration and the possible errors in judging the fire were considered to be too great when only approximately 300 pounds of coal were burned for each test. The calorific value of the fuel averaged 9,610 B.T.U. per pound, which is considerably lower than that of sub-bituminous coal No. 1 but higher than for the other four domestic coals.

The *quantity of fuel fired per therm delivered* varied from 16·34 to 18·76 pounds averaging 17·45 pounds per therm. This figure is high, and is not so good as would have been expected from its calorific value. The *quantity of refuse removed per ton of fuel fired* averaged 297 pounds, the highest figure for any of the Alberta coals, and the amount of clinker removed was excessive, averaging 43·7 per cent of the total refuse removed. The total refuse expressed as a percentage of the total fuel fired, averaged 14·9, a particularly high figure for the Alberta fuels. The fire-periods were 6 hours for low load, 5 hours for intermediate load, and 3 hours for high load.

The average *thermal efficiency* obtained was somewhat lower than the average for Alberta fuels, and was 59·8 per cent. The efficiencies ranged for this series from 55·5 per cent at high load to 63·8 per cent at low load. The low figure of 55·5 per cent was obtained when the furnace was being operated at high load and when the *loss due to heat carried away in the dry flue gases* seemed excessive due to the very high temperature and excess air conditions. The *loss due to steam formed, etc.*, varied from 5·9 per cent for one of the tests at intermediate load, to 6·6 per cent for the test at high load. This loss is about the average for the Alberta fuels. The *loss due to heat carried away in the dry flue gases* was 9·9 per cent at low load, 10·9 and 10·7 per cent at intermediate load, and 19·3 per cent at high load, averaging 12·7 per cent for the four tests. This average was unduly affected by the excessive loss at high load where the flue gas temperature and excess air were high as referred to above. The *loss due to unburned combustible matter in refuse* was about the same as the average for all the other Alberta fuels and averaged 5·0 per cent. This loss at low load was 5·9 per cent, 6·2 and 3·8 per cent at intermediate load, and 3·9 per cent at high load. The *loss due to unburned carbon monoxide* was very uniform for this series of tests. It varied from 1·0 per cent to 1·7 per cent averaging 1·3 per cent. The *balance of heat account, etc.*, was of about average quantity, averaging 15·2 per cent. It was 13·2 per cent at low load, 16·5 and 17·4 per cent at intermediate load, and 13·5 per cent at high load.

With the exception of domestic coal No. 5, this fuel is the least satisfactory of all the Alberta domestic fuels tested if purchased on the B.T.U. basis owing to its fairly high calorific value, viz., 9,610 B.T.U. per pound.

The average *quantity of fuel fired per therm delivered* was 17·45 pounds. The *quantity of refuse removed per ton of fuel fired* was exceptionally high, averaging for the four tests 297 pounds, showing that nearly 15 per cent of the total fuel fired is removed as refuse. Coupled with these disadvantages is a further one of a 6-, 5- and 3-hour fire-period necessary when operating this type of furnace at low, intermediate, and high loads.

ALBERTA DOMESTIC COAL NO. 3

This fuel is classed by the Scientific and Industrial Research Council of the province of Alberta as Alberta domestic. Seven tests in all were made on this fuel, three of which were of short duration and therefore are not included in this discussion. It was found expedient to use 6-, 5- and 3-hour fire-periods for low, intermediate, and high rates of combustion, although longer ones might have been employed but only at the sacrifice of the uniformity of the load curves. The calorific value of the fuel for two of the tests was 9,600 B.T.U. per pound and for the remaining tests, 9,470 B.T.U. per pound; the average value being 9,540 B.T.U. per pound, or practically the same calorific value as shown for domestic coal No. 2.

The *quantity of fuel fired per therm delivered* varied from 16·50 to 18·12 pounds, the average figure being 16·99 pounds per therm. This shows that for this series of tests domestic coal No. 3 was more economical to burn than domestic coal No. 2. The *quantity of refuse removed per ton of fuel fired* averaged 175 pounds, varying from 160 to 203 pounds per ton, the high figure being for the test at the lowest load. This average figure is the lowest for all tests on the Alberta fuels. Clinkers were formed during all the tests and the average value for the four tests was 43·5 per cent of the total refuse removed, practically the same figure as for domestic coal No. 2. Only 8·8 per cent of the fuel fired was removed in the form of refuse. This fuel with domestic coal No. 1 gave the lowest value for this item of all the Alberta fuels tested.

The *thermal efficiencies* for the four tests ranged from 57·5 per cent to 63·8 per cent, giving an average of 61·8 per cent. These figures are about the average of those obtained for all the Alberta fuels tested. The *loss due to steam formed, etc.*, averaged 6·4 per cent. The *loss due to heat carried away in the dry flue gases* varied from 8·8 per cent at the lowest load to 15·7 per cent at the highest load; these are exceptionally low figures for this series. The *loss due to unburned combustible matter in refuse* averaged only 3·4 per cent. The *loss due to unburned carbon monoxide* ranged from 0·9 to 3·0 per cent and averaged 1·8 per cent for the four tests. The *balance of heat account, etc.*, averaged 15·4 per cent and is slightly higher than the average for the nine Alberta fuels tested.

These tests show that domestic coal No. 3 is a very satisfactory one when burned in this type of heater, in comparison with the other Alberta domestic fuels. The value (quantity of fuel fired per therm delivered) is slightly above the average and the quantity of refuse removed per ton of fuel fired is remarkably low. This latter point is a feature which weighs quite heavily with the average householder. No serious difficulties were encountered due to clinkering and the clinker which formed was easily broken up and removed.

ALBERTA DOMESTIC COAL NO. 4

The Scientific and Industrial Research Council of the province of Alberta classes this fuel as Alberta domestic. Four tests were made: one at low load, two at intermediate load, and one at high load. The duration of tests were 90 hours at low load, 65 hours at intermediate load, and 42 hours at high load. Approximately 1,000 pounds of fuel were consumed for each test. Fire-periods of 6, 5, and 3 hours were adopted for the four tests. The calorific value of the fuel varied from 8,960 to 9,110 B.T.U. per pound, the slight variation being due to errors in sampling the fuel.

The *quantity of fuel fired per therm delivered* averaged 17·51 pounds, varying from 16·53 pounds at low load to 18·73 pounds at high load, which clearly shows that this type of furnace should never be operated at such a high rate when burning this class of fuel. The *quantity of refuse removed per ton of fuel fired* varied from 245 pounds at low load to 268 pounds for one of the tests at intermediate load, averaging 255 pounds per ton. The average refuse removed when expressed as a percentage of the total fuel fired was 12·7. This figure is high for the Alberta fuels, although not so high as the same figure for domestic coal No. 2 and Alberta semi-bituminous coal. Clinkers were formed during every test, and the figures for the amount of clinker produced, when expressed as a percentage of the total refuse removed, were as follows: 23·3 at low load, 27·9 and 31·5 at intermediate loads, and 58·4 at high load.

The *thermal efficiencies* obtained were high, averaging 63·3 per cent and ranging from 59·6 per cent at high load to 67·5 per cent at low load. These figures were the highest obtained for any of the Alberta coals with the exception of the semi-bituminous coal which averaged a little higher than 66 per cent. The *loss due to steam formed, etc.*, averaged 6·2 per cent. The *loss due to heat carried away in the dry flue gases* varied from 10·4 per cent at low load to 20·9 per cent at high load, with an average of 13·5 per cent. The *loss due to unburned combustible matter in refuse* was low; the average was 3·0 per cent which was slightly higher than the same loss for sub-bituminous coal No. 3. On the other hand, the *loss due to unburned carbon monoxide* averaged 1·8 per cent, the highest figure obtained for this loss when testing Alberta fuels. The *balance of heat account, etc.*, was low, though not quite so low as when testing Alberta semi-bituminous coal.

This fuel, though low in calorific value, gave very excellent results. The quantity of fuel fired per therm delivered was comparatively low. The amount of refuse removed per ton of fuel fired was fairly high averaging 12·7 per cent.

ALBERTA DOMESTIC COAL NO. 5

The Scientific and Industrial Research Council of the province of Alberta classed this fuel as Alberta domestic. Seven tests were made on the fuel, only four of which are discussed here. The calorific value of the fuel as determined by sampling and analysis for each test averaged 8,770 B.T.U. per pound, the values ranging from 8,700 to 8,840 B.T.U. per pound.

This fuel had the lowest calorific value of any of the coals tested. It had also the highest moisture content. However, the ash content was a little lower than the average for the Alberta fuels.

The *quantity of fuel fired per therm delivered* varied from 18·73 pounds at the lowest load to 19·42 pounds at the highest load, a very high figure in comparison with the Alberta semi-bituminous and sub-bituminous coals. The *quantity of refuse removed per ton of fuel fired* averaged 211 pounds. Clinkers were formed but they did not prove troublesome. On the average, 23 per cent of the refuse removed was in the form of clinker and was taken out through the fire-door. The refuse removed, expressed as a percentage of the total fuel fired, varied from 8·8 to 11·8 per cent, averaging 10·6 per cent, and was slightly higher than the same figure for sub-bituminous coal No. 1. The fire-periods adopted for this series of tests were 6 hours for low load, 5 hours for intermediate load, and 3 hours for the highest load.

The *thermal efficiencies* obtained were 61·4 per cent at the lowest load, 59·8 and 58·9 for the intermediate loads, and 59·2 per cent for the highest load, the average being 59·8 per cent. These figures are a little lower than the average for the Alberta coals, and may be accounted for by the high *loss due to steam formed, etc.*, which averaged 7·2 per cent for the four tests. The *loss due to the unburned combustible matter in refuse* averaged 5·9 per cent. This is higher than for any of the other Alberta fuels with the exception of the semi-bituminous coal. The *loss due to unburned carbon monoxide* ranged from 1·4 to 2·4 per cent with an average of 1·9 per cent. This value is also higher than that obtained for any of the other Alberta fuels. The *balance of heat account, etc.*, was quite low, averaging 13·6 per cent and varied from 10·4 per cent at the highest load to 17·6 per cent for one of the intermediate loads.

The average figure for quantity of fuel fired per therm delivered was very high, viz., 19·06 pounds. Coupled with this high figure the necessary short fire-period makes this fuel the least desirable for domestic use. To offset these two disadvantages, however, the quantity of refuse removed per ton of fuel fired was a little lower than the average for the series of tests on Alberta coals. It was clean to handle and gave no undue trouble with clinker. Only 23 per cent of the total refuse was removed in the form of clinker.

WELSH BRIQUETTES

Only 1,700 pounds of this fuel were available for test purposes and this was sufficient to make only one test. This test was made at the low rate of combustion of 72,000 B.T.U. per hour. The calorific value of this fuel was 13,380 B.T.U. per pound, and the *quantity of fuel fired per therm delivered* was 12·18 pounds. An 8-hour fire-period was adopted for the test which was of 96 hours' duration. The *quantity of refuse removed per ton of fuel fired* was 374 pounds, about the same as the average figure obtained when testing American anthracite which was the highest value noted for the fuels tested. The total amount of refuse removed was 157 pounds, or 18·7 per cent of the total fuel fired.

The *thermal efficiency* obtained was 61·4 per cent, a very low figure, and may be explained by the fact that a test run of no more than a few hours could be made on this fuel to acquaint the observers with the best methods of firing and of setting the draughts, etc. No gas analyses were made when testing this fuel, and in consequence, a heat balance could not be worked out with the exception of the *loss due to unburned combustible matter* which was found to be 10·8 per cent.

It is impossible on the evidence obtained from one test, to comment on the behaviour of this fuel beyond stating that it was very smoky when a fresh charge of fuel was placed on the fire and that great care had to be taken not to poke the fire nor to shake the grates too vigorously, otherwise a great deal of combustible matter would be wasted by falling into the ash-pit.

AIR-DRIED MACHINE PEAT

Two tests were conducted on this fuel, one with a fire-period of 5 hours and the other with a fire-period of 2½ hours. The excess air for the first test was found to be 202 per cent and for the second test only 72 per cent. On account of this high value the first test was disregarded. The calorific value of the fuel for the test here considered was 7,350 B.T.U. per pound. The fire-period, as stated above, was 2½ hours. The *quantity of fuel fired per therm delivered* was 25·00 pounds, which value was higher than for any other fuel tested. The *quantity of refuse removed per ton of fuel fired* was exceedingly low, being only 79 pounds, which value was lower than for any other fuel, being equivalent to 4 per cent of the fuel fired. No clinker was formed.

The *thermal efficiency* for this test was 54·4 per cent, a very low figure but not so low as might be expected after a study of the analysis of the fuel, which shows that the volatile matter was in the neighbourhood of 47 per cent, and the fixed carbon only 23·5 per cent. The *loss due to steam formed, etc.*, was 10·1 per cent, the highest figure for this loss during the entire investigation. The *loss due to heat carried away in the dry flue gases* was 8·0 per cent, and is, therefore, about an average value for the fuels tested. The *loss due to unburned combustible matter in refuse* was exceedingly low, viz., 1·8 per cent. The *loss due to unburned carbon monoxide* was 1·1 per cent, and is therefore a little higher than the average. The *balance of heat account, etc.*, was very high, viz., 24·6 per cent.

This fuel is very clean to handle and disintegrates very little on storage. It is very readily kindled and the fuel will smoulder away for days at a time with apparently no draught. On the other hand, it is not an economical fuel to burn in this type of furnace when a steady heat is required, but as an auxiliary fuel, in the sense that wood might be termed an auxiliary fuel, it is excellent, that is, when a little heat is wanted for a few hours in the morning, and then again for a few hours during the evening. The ash does not clinker and the grates do not require shaking. All that is necessary is to poke the ashes a little on the grates in order to uncover the glowing embers of the fuel left from a previous fire.

SUMMARY

The fuels tested may be roughly divided into three groups: first, those having a high fixed carbon content varying from 75 to 92 per cent, viz., the anthracites and cokes; second, those having a fixed carbon content of from 70 to 74 per cent which are the semi-bituminous coals including the one from Alberta; third, those having a fixed carbon content of from 40 to 51 per cent which are the Alberta sub-bituminous and domestic coals. To the third group might be added air-dried, machine peat, which has a fixed carbon content of only 22 per cent; and the last fuel, Welsh briquettes, which has a fixed carbon content of 76·1 per cent, should be placed in the first group.

GROUP NO. 1—ANTHRACITES AND COKES

The first group is characterized by the high thermal efficiencies with which these fuels were burned during the tests. The average efficiency obtained for all these fuels in this group was 72·9 per cent, and the quantity of fuel fired per therm delivered averaged 10·78 pounds. A further characteristic of this group was the small amount of refuse removed per ton of fuel fired, with the exception of American anthracite, and by-product coke No. 1, where the refuse removed was exceedingly high. The unaccounted for loss of all the tests made on the fuels in this group was fairly low, being the least for American anthracite and the greatest for by-product coke No. 3.

The high efficiencies obtained when testing these fuels might well be expected on account of the fact that the furnace had been designed to burn fuels high in fixed carbon and low in volatile matter content and particularly for the burning of anthracites, and on that account it might be expected that these figures for this fuel would be higher than the figure for the cokes. Although the cokes have a higher percentage of fixed carbon, there is some characteristic of this fuel which makes it more difficult to burn with as high an efficiency as the anthracites. This factor or characteristic is unknown to the writers but it undoubtedly exists. This group of fuels is further characterized by the small amount of attention required when burning them and by the almost entire absence of clinker formation except when burned at extremely high rates of combustion.

GROUP NO. 2—SEMI-BITUMINOUS COALS

The thermal efficiencies with which the second group of fuels were burned averaged 65·8 per cent. In this group the average figure for the quantity of fuel fired per therm delivered was 11·07 pounds, being slightly higher than the same figure obtained for group No. 1. The quantity of refuse removed per ton of fuel fired was slightly lower than the average figure obtained for the first group of fuels.

To offset the advantage obtained due to the smaller quantity of refuse, the attendance required when burning these fuels is considerably more than when burning the anthracites and cokes, although the fire-periods were of the same length, viz., 8 hours for low and intermediate loads, and 6 hours for high load.

GROUP NO. 3—ALBERTA SUB-BITUMINOUS AND DOMESTIC COALS

The fixed carbon content of the fuels placed in group No. 3 varied from 39·8 to 50·5 per cent. This is not including peat fuel which has a fixed carbon content of only 22 per cent. The thermal efficiencies with which the third group of fuels were burned varied from 58·5 to 63·3 per cent and with peat was 54·4 per cent. These efficiencies might be considered fairly high when the low value of the fixed carbon content of these fuels is considered. However, the thermal efficiencies are distinctly lower than for the other two groups, averaging only 60·8 per cent. The quantity of fuel fired per therm delivered varied from 19·06 in the case of domestic coal No. 5 to 14·77 in the case of sub-bituminous coal No. 1, a very wide variation and considerably greater than the same for groups Nos. 1 and 2. The refuse removed per ton of fuel fired was about the same as the average for the other two groups, with the difference that a greater percentage of the refuse was removed in the form of clinker through the fire-door. The attendance required when burning the fuels in group No. 3 was considerably greater than that required when burning the fuels in either of the other two groups. The fire-periods varied from 4 to 8 hours for the better grade fuels of this class and from 3 to 6 hours with the others. In the case of peat it was found necessary to fire every 2½ hours, and even with that short fire-period combustion could only be maintained at a low rate. Greater care has to be exercised in building fires with these fuels than with the fuels in either of the other two groups, in order to burn the combustible gases as they are given off from the fuel bed and to render them comparatively smokeless. To accomplish this it was also necessary to leave the fire-door grid open to its widest extent and in many cases the door itself open slightly. The efficiencies obtained were very high when it is considered that the furnace was designed for burning fuels with a comparatively low volatile matter content, whereas these fuels were all high in this respect.

ECONOMIC RESULTS

Table X shows the relative values of the fuels tested, compared with American anthracite, based on quantity of fuel fired per therm delivered. The column headed "equivalent tonnage to 10 tons of American anthracite" is a comparison of all the fuels with American anthracite, on a basis of heat delivery only. This column shows that Welsh anthracite is the most economical fuel and that all the Alberta fuels, with the exception of Alberta semi-bituminous coal, required from 12·96 to 16·73 tons to equal 10 tons of American anthracite. It must be remembered that this comparison is based on a single series of tests and might not apply to all types of furnaces, although it is safe to take the results of this series as a rough comparison of one fuel with another.

TABLE X

Showing the Relative Values of Various Fuels tested, compared with American Anthracite and based on Quantity of Fuel fired per therm (100,000 B.T.U.) delivered to the Cooling Water of the System

	Fuel	Pounds of Fuel Fired per Therm (100,000 B.T.U.) delivered to the cooling water								Equivalent tonnage to 10 tons of American anthracite
		Values for each of the tests selected for charting and tabulation							Average value	
1	American anthracite......	10·95	11·44	10·80	12·36	......	......	......	11·39	10·00
2	Welsh anthracite..........	9·60	9·78	9·48	9·35	9·57	......	......	9·56	8·39
3	Scotch semi-anthracite....	9·44	9·57	9·68	10·24	......	......	......	9·73	8·54
4	Gas coke..................	11·45	11·20	10·93	10·82	10·96	11·36	11·76	11·21	9·84
6	By-product coke No. 2....	10·18	10·34	10·25	10·57	......	......	......	10·33	9·07
7	By-product coke No. 3....	10·50x	10·91	11·16	10·83	......	......	......	10·85	9·53
8	By-product coke No. 4....	10·83x	10·23x	11·38x	......	......	......	......	10·81	9·49
9	American smokeless, semi-bituminous No. 1........	10·97	10·91	10·72	11·30	......	......	......	10·97	9·63
10	American smokeless, semi-bituminous No. 2........	10·55	11·20	11·03	11·25	......	......	......	11·01	9·67
11	Alberta semi-bituminous..	11·18	11·34	11·19	11·39	......	......	......	11·27	9·89
12	Alberta sub-bituminous No. 1....................	13·89	15·27	14·90	14·99	......	......	......	14·76	12·96
13	Alberta sub-bituminous No. 2....................	15·04	15·18	15·82	16·16	......	......	......	15·55	13·65
14	Alberta sub-bituminous No. 3....................	14·46	16·08	16·26	16·98	......	......	......	15·94	13·99
15	Alberta domestic No. 1....	16·03	17·30	16·98	18·25	......	......	......	17·14	15·05
16	Alberta domestic No. 2....	16·34	17·51	17·18	16·76	......	......	......	17·45	15·32
17	Alberta domestic No. 3....	16·56	16·81	16·56	18·12	......	......	......	17·01	14·93
18	Alberta domestic No. 4....	16·53	17·34	17·45	18·73	......	......	......	17·51	15·37
19	Alberta domestic No. 5....	18·73	18·90	19·19	19·42	......	......	......	19·06	16·73
21	Air-dried, machine peat...	25·00x	....	....	......	......	......	......	25·00	21·95

x Denotes tests of short duration. See page 28, paragraph 4 for explanation short and long tests.